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NORAIR DIVISION
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EXPERIMENTAL AND THEORETICAL INVESTIGATION
OF A REICHARDT BODY OF REVOLUTION WITH LOW
DRAG SUCTION IN THE NASA-AMES
12 FT. PRESSURE WIND TUNNEL

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DATE

PAGE

REF ID:

ROR-63-44 (QLC-14)

MODEL

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11

REPORT NO.

NORD-62-111-117
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SUMMARY

Full length laminar flow with very low friction and equivalent total drags was maintained on an 8 to 1 fineness ratio Reichhardt body of revolution of 12-foot length by means of boundary layer suction through 113 fine slots up to a length Reynolds number $R_L = 57,76 \times 10^6$. The lowest coefficient of equivalent total drag (based on body wetted area and including the equivalent suction drag) at an angle of attack $\alpha = 0^\circ$ was $C_{D_t} = 2.63 \times 10^{-4}$ at $R_L = 57,76 \times 10^6$ with a corresponding total suction flow coefficient (based on wetted area) $C_{Q_t} = 1.77 \times 10^{-4}$. This value of equivalent total drag is 12 percent of the friction coefficient of a turbulent flat plate at this length Reynolds number.

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NORTHROP CORPORATION
NORAIR DIVISION

111
REPORT NO.
NOR-63-46 (M.S.-1)
VOLUME

TABLE OF CONTENTS

	<u>Page</u>
ACKNOWLEDGEMENTS	1
SUMMARY	ii
NOTATION	iv
I. INTRODUCTION	1
II. EXPERIMENTAL STUDY	3
A. Experimental Setup	3
B. Measurements and Evaluation	6
C. Experimental Results	10
III. THEORETICAL STUDY	13
A. Computation Procedure	13
B. Theoretical Results	14
IV. DISCUSSION	15
REFERENCES	18
LIST OF TABLES AND FIGURES	20

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 L. W. Gross
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 DATE

NORTHROP CORPORATION
NOVAIR DIVISION

PAGE
 IV
 REPORT NO.
 NOVA-6.1-46 (100-140)
 MODEL

NOTATION

$c_p(\varphi)$ local drag contribution of boundary layer momentum thickness at a given radial angle φ

C_D = $\frac{D}{q_\infty S}$; coefficient of drag, based on body wetted area S

C_{D_s} = $\sum_{\text{all chambers}} c_{Q_a} (1 - c_{p_a})$; coefficient of drag due to suction

power required to accelerate the suction air without losses to undisturbed velocity and pressure

C_{D_t} = $C_{D_s} + C_{D_w}$; coefficient of equivalent total drag

$C_{D_t \min}$ minimum equivalent total drag coefficient

C_{D_w} = $\int_0^{2\pi} c_{D_w} d\varphi$; coefficient of wake drag

c_f laminar flat plate friction coefficient

c_p = $\frac{p - p_\infty}{q_\infty}$; pressure coefficient with respect to ambient

static pressure p_∞

c_{p_a} = $\frac{p_a - p_\infty}{q_\infty}$; pressure coefficient of individual suction

chamber with respect to ambient static pressure p_∞

c_{Q_a} = $\frac{Q_a}{U_\infty S}$; suction coefficient of individual suction chamber

based on body wetted area S

2-7A
21

ENGINEER L. W. Gross	CHECKER	DATE
-------------------------	---------	------

NORTHROP CORPORATION
NORAIR DIVISION

PAGE
V
REPORT NO.
NOR-63-46 (BUC-168)
MODEL

$$C_{Qt} = \sum_{\text{all chambers}} C_{Qa} ; \text{ total suction coefficient}$$

$C_{Q \text{ opt}}$ optimum total suction coefficient corresponding to minimum equivalent total drag

D drag (lb)

H $= \frac{\delta^*}{\theta}$; boundary layer shape parameter

\bar{H} average boundary layer shape parameter between the value at the boundary layer rake position and the value at infinity

H_{TE} boundary layer shape parameter at the boundary layer rake position of the model

L model length = 12.0 ft.

p_a pressure in the individual suction chamber (lb/ft^2)

p_∞ undisturbed freestream static pressure (lb/ft^2)

$q_\infty = \frac{1}{2} \rho U_\infty^2$; undisturbed freestream dynamic pressure (lb/ft^2)

Q_a suction quantity of individual suction chamber (ft^3/sec)

r body radius at axial station x (ft)

r_{TE} body radius at the boundary layer rake position of the model ≈ 3.345 in.

$R_L = \frac{U_\infty L}{v}$; Reynolds number based on model length L

$R_\theta = \frac{U_\infty \theta}{v}$; Reynolds number based on boundary layer momentum thickness θ

s distance along the surface of the model (ft.)

S wetted surface area of model = 46.23 ft^2

u velocity in the boundary layer at height y (ft/sec)

20-7A
68)

L. W. Gross	NORTHROP CORPORATION NORAIR DIVISION	PAGE VI
CHIEF		REPORT NO NOR-63-45 (BLG-148)
DATE		MODEL

- u velocity at the outer edge of the boundary layer (ft/sec)
 U_{TE} potential flow velocity at the boundary layer rake position of the model (ft/sec)
 U_∞ undisturbed freestream velocity (ft/sec)
 v_0 suction inflow velocity for equivalent area suction (ft/sec)
 v_0^* $= \frac{v_0}{U_\infty} \sqrt{R_L}$; nondimensional suction inflow velocity for equivalent area suction
 x distance along axis of model (ft)
 y distance normal to the surface of the model (ft)
 α angle of attack (degrees)
 δ boundary layer thickness (ft)
 δ^* $= \int_0^\delta \frac{u}{U} (1 + \frac{y}{r}) dy$; boundary layer displacement thickness (ft)
 δ_{TE}^* boundary layer displacement thickness at the boundary layer rake position of the model
 θ $= \int_0^\delta \frac{u}{U} (1 - \frac{u}{U}) (1 + \frac{y}{r}) dy$; boundary layer momentum thickness (ft)
 θ_{TE} boundary layer momentum thickness at the boundary layer rake position of the model
 θ_∞ wake momentum thickness far behind the model
 μ absolute viscosity (lb - sec / ft²)

0-7A
62)

ENCOUNTER	L. W. Gross
CHECKER	
DATE	

NORTHROP CORPORATION
NORAIR DIVISION

PAGE 111
REPORT NO.
NOR-63-46 (Rev. 14)
Model

$\nu = \frac{\mu}{\rho}$; kinematic viscosity (ft^2/sec)

ρ density ($\text{lb} - \text{sec}^2/\text{ft}^4$)

ψ radial angle (degrees)

ENGINEER	L. W. Gross
CHECKER	
DATE	

NORTHROP CORPORATION
NORAIR DIVISION

PAGE	1
REPORT NO.	NOR-63-43 (PLG-16)
MODEL	

I. INTRODUCTION

Substantial performance increases of underwater bodies would be possible if extensive or completely laminar boundary layer flow could be maintained over their surfaces by means of boundary layer suction (reference 2 through 5). The question therefore arises as to whether laminar flow can be maintained on underwater bodies of revolution up to the length Reynolds numbers encountered by such bodies cruising at high speeds. In addition, it is desirable to establish data from which the limits of the parameters significant to boundary layer stability on a body of revolution can be deduced for design purposes.

Low drag suction experiments are generally considerably easier to conduct in low turbulence wind tunnels than in water. Since similar flows develop in water and air for the same Reynolds numbers, as long as effects from a free surface and cavitation can be neglected, it was decided to investigate a Reichardt body of revolution of fineness ratio 8, with low drag suction applied through 113 slots, in the Ames 12-foot low turbulence high pressure tunnel. The low level of turbulence and noise of the Ames 12-foot tunnel at high tunnel pressures (reference 6) should enable the maintenance of full length laminar flow on the Reichardt suction body up to considerably higher length Reynolds numbers than the maximum value of 18×10^6 which was observed during the first experiments on the same suction body in the NORAIR 7- by 10-foot atmospheric low turbulence tunnel (reference 1).

ENGINEER	L. W. GROSS	NORTHROP CORPORATION NORAIR DIVISION	PAGE
CHECKER			2
DATE		REPORT NO. NOR-63-46 (M.C. 1/3) MODEL	

II EXPERIMENTAL STUDY

A. EXPERIMENTAL SETUP

The body shape was an 8:1 fineness ratio Reichardt body of revolution (reference 8) and was chosen to allow comparison with a test model built by the U.S. Naval Ordnance Test Station (NOTS), Pasadena, California, and described in reference 4. The diameter of the Norair model was 18 inches and the body length 144 inches. At the rear of the body was a 6.5 inch diameter sting which served to support the model and provide a passage for ducting suction air out of the model. The body shape was faired smoothly into the sting from 94 to 103% of the body length, using an algebraic equation with five unknowns to allow matching of the ordinate and first and second derivatives of the body shape as well as the ordinate and first derivative of the sting. The final model contour is illustrated in Figure 1 and the coordinates of the shape are given as Table I.

The potential pressure distribution of the body (without sting and at $\alpha = 0^\circ$ angle of attack) was computed for NOTS by A.M.O. Smith, using the method of reference 9, and was experimentally checked by Norair with a nonsuction Reichardt body of revolution utilizing a sting (reference 1, appendix A). The theoretical pressure distribution is shown in Figure 5.

Based on previous low drag suction experiments on a 30° swept laminar suction wing (reference 7) in the Norair 7- by 10-foot and in the Ames 12-foot tunnel and other low drag suction investigations in the Norair 7- by 10-foot tunnel it was estimated that full length laminar

1-78 19)	MANUFACTURER'S NAME & ADDRESS ENGINEER L. W. Gross	TYPE OF REPORT NORTHROP CORPORATION AIR DIVISION	PAGE 3
	CHECKER	REPORT TO NOR-EN-40 (BLG-14)	
	DATE	MODEL	

flow should be feasible on the Kellhardt body with low drag suction in the Ames 12-foot tunnel up to 40×10^6 to 50×10^6 length Reynolds number. Accordingly, the model was laid out for a design length Reynolds number $R_L = \frac{U_{\infty} L}{v} = 49 \times 10^6$. The boundary layer development along the body was calculated (Figure 6) by means of Naeta's method (reference 10), using the potential flow pressure distribution and the theoretical suction distribution (for equivalent area suction) shown in Figure 6.

On the front part of the body the boundary layer is rather unstable due to the stretching of disturbance vortices in the boundary layer in the region of increasing body radius. In order to rapidly stabilize the boundary layer in this forward area relatively strong suction was applied far forward, followed by decreasing suction in the region of the flat pressure distribution. In order to avoid an excessive thickening of the boundary layer and laminar separation and transition in the region of the rear pressure rise and decreasing body radius, considerably stronger suction was applied in this area of the body. Area suction, being optimum aerodynamically, was closely approached by means of suction through 113 0.003" wide slots located from 2.75% to 99.6% of the body length. The position of the first slot was selected on the basis of transition experiments on a nonsuction Rechardt body of revolution (appendix A of reference 1) extrapolated to high Reynolds numbers. Figure 1 shows the model and details of the suction system. The slot spacing was determined from the theoretical boundary layer development (Figure 6) to be two inches in the region of the flat pressure distribution from 2.5% to 80% of the body

ENGINEER	L. W. Gross	PAGE	4
CHECKER	NORTHROP CORPORATION NORAIR DIVISION	REPORT NO.	
DATE		NOR-63-46 (BLC-148)	MODEL

length and one-half inch in the region of the rear pressure rise from 80% to 99.6% of the length where strong suction is required. In order to avoid local flow decelerations at the slot inlets which might lead to flow instabilities in the boundary layer the slot width was chosen approximately equal to the thickness of the sucked boundary layer at the design length Reynolds number of $49 \cdot 10^6$. The suction air passed through the slots and circumferential grooves or small plenum chambers, through holes, drilled in a thicker continuous inner skin, into 13 individual suction chambers. These holes at the same time acted as suction flow metering holes. In addition, in order to avoid any local flow separation at the inlet of the sharp edged suction slots and suction holes located underneath the slots the Reynolds numbers in these slots and holes (based on slot width or hole radius and mean velocity through the slots or holes) was restricted to such low values that the flow through the slots and holes was purely viscous.

The model was built up of an inner shell composed of seven machined tubes bolted together, a nose piece, and outer rings shrunk-fit to the inner shell. Details of the slot and hole system are given in Table II. Suction plenum chambers were turned into the outer rings. During assembly, the outer rings were forced together as they were shrunk-fit onto the inner shell and the slots were subsequently turned into the joint between rings to provide positive control of the slot width. Compartmentation of the model into thirteen suction chambers was accomplished by means of sealed bulkheads. Calibrated suction flow measuring nozzles were mounted in the face of the bulkheads.

ENGINEER	L. W. Gross	PAGE	5
CHECKER	NORTHROP CORPORATION NORAIR DIVISION	REPORT NO.	NOR-63-46 (BLC-146)
DATE		MODEL	

Figure 2 is a schematic drawing of the model as it was installed in the NASA-Ames 12-foot pressure wind tunnel and Figure 3 shows the model as it appeared in the wind tunnel test section. Disturbances from the model support system were minimized. The model was held by a tubular sting extension which, in turn, fitted into the body of revolution of the wind tunnel high-speed support system. Streamline sway braces, extending from the sting extension to the wind tunnel walls, were provided as a guard against flutter and could be used to make slight adjustments of the angle of yaw of the model.

From the suction chambers, the suction air passed through calibrated suction flow measuring nozzles mounted in the various bulkheads, and through aluminum tubes to the exterior of the model. Flexible tubing led the suction air out of the test section through fairings fixed to the high-speed support system and to a common suction box located in the wind tunnel balance chamber. Since the experiments were conducted at tunnel pressures varying from two to five atmospheres, suction could be operated by bleeding the suction air into the atmosphere through a sonic throat. The individual suction quantities of the various suction chambers were varied by means of remotely adjustable needle valves located at the inlets to the common suction box and the total rate of suction was controlled by remotely varying the area of the sonic throat.

Flow disturbances from the internal ducting system which might adversely affect the boundary layer on the external surface were minimized by avoiding local flow separations and flow pulsations in the ducting system and by maintaining a steady and uniquely defined duct flow.

ENGINEER L. W. GROES	NORTHROP CORPORATION NORAIR DIVISION	PAGE 6
CHECKER		REPORT NO. NOR-63-46 (BLC-148)
DATE		MODEL

B. MEASUREMENTS AND EVALUATION

The objective of this investigation was the study of the behavior of the laminar boundary layer on a Reichardt body of revolution with suction through many fine slots and the determination of the drag characteristics and suction requirements of this body at various Reynolds numbers R_L . At each Reynolds number the suction quantities were varied over a range that included the point of minimum drag.

The pressure drop across the calibrated flow measuring nozzles located at the downstream end of the various suction chambers was measured to evaluate the suction quantities Q_a of the individual suction chambers. The corresponding chamber static pressures were taken at the downstream end of the suction chambers. The lengthwise pressure distribution was recorded by means of twenty-one static pressure orifices located from 2 to 95% of the length. The location of the static pressure orifices is given in Table III. In order to properly set the model at an angle of attack $\alpha = 0^\circ$, four pressure taps arranged 90 degrees from each other were provided at a station 3% of the body length from the nose.

For the determination of the wake drag of the model, the boundary layer velocity profiles at the aft end of the body were measured by means of six boundary layer rakes. The rakes were located at radial stations $\varphi = 0^\circ$ (top of model), 30° , 60° , 180° , 225° and 270° (see Figure 4). Four of the rakes ($\varphi = 0^\circ$, 30° , 180° and 225°) each consisted of twelve flattened total pressure tubes whereas the remaining two ($\varphi = 60^\circ$ and 270°)

L. W. Gross	NORTHROP CORPORATION NORAIR DIVISION	7
CHECKER		REPORT NO. NOR-6-46 (BLC-148)
DATA		MODEL

consisted of twelve 0.010-inch diameter round total pressure tubes apiece. Round total pressure tubes, which are less sensitive to angle of attack, were used for the side rakes to minimize errors at angles of attack. Each of the rakes had two static pressure tubes displaced one-half inch from the plane of the total pressure tubes.

The state of the boundary layer was observed from the boundary layer measurements at the aft end of the body.

The static pressures in the measuring nozzles, suction chambers and on the external body surface were displayed on a first U-tube manometer panel. The boundary layer rake readings (total and static pressures) were recorded on a second, separate U-tube manometer board. In this manner fluctuations of the total pressure readings from the rakes did not influence the remaining pressure readings. The pressure data were recorded photographically on 70-mm film, which was then read on a filmreading machine. The recording was on punched cards suitable for use on an IBM 7090 digital computer.

The undisturbed freestream static and dynamic pressures p_∞ and q_∞ were determined from wind tunnel calibration curves and calculations of the tunnel wall corrections by the wind tunnel staff. The resultant minimum pressure coefficients showed a scatter of $\pm 0.6\%$ of freestream dynamic pressure.

From the measured suction quantities Q_s in the various suction chambers the suction quantity coefficients $C_{Q_s} = \frac{Q_s}{U_\infty S}$ of the individual chambers

L. W. Gross

CHECKER

DATE

NORTHROP CORPORATION
NORAIR DIVISION

8

REPORT NO.

NOR-63-46 (ELC-148)

MODEL

and the coefficient $C_{p_a} = 1 - \frac{P_a - P_\infty}{q_\infty} = 1 - C_{p_a}$ of the isentropic pressure rise across a suction compressor necessary to accelerate the suction air to freestream velocity and ambient static pressure without losses, the equivalent suction drag coefficient is

$$C_{D_s} = \sum_{\text{all chambers}} C_{Q_a} (1 - C_{p_a}).$$

Due to the surface curvature of the body at the rake location, a pressure gradient normal to the body existed and was measured by the two static pressure probes mounted on each rake. A linear variation of static pressure was assumed for the determination of the velocity distribution in the boundary layer at the rake location.

For the evaluation of the wake drag, it was assumed that the measured boundary layer profile is first accelerated over a short distance to a constant static pressure equal to the value at the edge of the boundary layer at the rake location. This new fictitious boundary layer profile at constant static pressure can be determined from the continuity and Bernoulli equations (i.e., assuming constant total pressure along streamlines). The wake momentum loss at infinity, which determines the wake drag, can then be evaluated from the momentum thickness of this fictitious boundary layer at constant static pressure according to Squire and Young:

$$C_{D_w} = \frac{2}{S} \int_0^{2\pi} r \theta_e d\varphi = \left(\frac{U_{Tg}}{U_\infty} \right)^{\bar{H}+2} \int_0^{2\pi} \frac{2 r_{TE} \theta_{TE}}{S} d\varphi$$

where r_{Tg} is the body radius at the measuring station, U_{Tg} is the potential

5-621
ENGINEER: L. W. Gross
CHECKER:
DATE:

NORTHROP CORPORATION
NORAIR DIVISION

PAGE 9
REPORT NO.
NOR-63-46 (BLG-14R)
MODEL

flow velocity at the edge of the boundary layer, \bar{H} is the value of $H = \frac{\delta^*}{\delta}$

in the wake between the boundary layer rake position and infinity and

$$\theta_{TE} = \int_0^{\delta} \frac{u}{U} \left(1 - \frac{u}{U}\right) \left(1 + \frac{y}{r_{TE}}\right) dy$$

$$\delta^*_{TE} = \int_0^{\delta} \left(1 - \frac{u}{U}\right) \left(1 + \frac{y}{r_{TE}}\right) dy$$

Shortly downstream of the rear end of the model $H_{TE} = 1.4$ (turbulent) and $H = 1.0$ at infinity; therefore, $\bar{H} + 2 = 3.2$, and

$$c_{Dw} = \left(\frac{U_{TE}}{U_\infty}\right)^{3.2} \int_0^{2\pi} 2 \frac{r_{TE} \theta_{TE}}{s} d\varphi$$

For the determination of the total wake drag the momentum thickness as measured by each boundary layer rake (at radial position φ) was determined and a "local" wake drag $c_{Dw}(\varphi)$ was defined as

$$c_{Dw} = \left(\frac{U_{TE}}{U_\infty}\right)^{3.2} \times 2 \frac{r_{TE} \theta_{TE}}{s}$$

At an angle of attack $\alpha = 0^\circ$ the total wake drag was then determined from the average value of the local wake drags so that

$$c_{Dw} = 2\pi \times \left[c_{Dw}(0) + c_{Dw}(30) + c_{Dw}(60) + c_{Dw}(180) + c_{Dw}(225) + c_{Dw}(270) \right]$$

6

The equivalent total drag is then the sum of the wake and equivalent suction drags:

$$c_{Dt} = c_{Dw} + c_{Ds}$$

ENCLOSURE	L. W. GROSS	NORTHROP CORPORATION NORAIR DIVISION	PAGE 10
CHECKER			REPORT NO. NOR-63-46 (RLC-148)
DATE			MODEL

C. EXPERIMENTAL RESULTS

The experimentally determined lengthwise potential flow velocity distribution is shown in Figure 5 and compared with the theoretical potential flow velocity distribution as calculated by the method of reference 9. The experimental and theoretical potential flow velocity distributions agree within 0.2 percent of the freestream velocity. The experimental curve is consistently higher than the theoretical curve in the region from 25 to 70 percent of the length indicating a slight error in the determination of the freestream velocity.

Figures 7 through 52 show the variation of the wake drag coefficient C_{D_w} , the equivalent suction drag coefficient C_{D_s} and the equivalent total drag coefficient C_{D_t} as a function of the total suction flow coefficient C_{Q_t} . At low suction rates, increasing suction moves transition back towards the end of the body, causing a rapid decrease in wake drag and total drag. As suction is increased further, and turbulent bursts are eliminated entirely, the fully laminar boundary layer is merely thinned by additional suction. Since the corresponding decrease of wake drag due to thinning of the laminar boundary layer with increased suction is smaller than the corresponding increase in equivalent suction drag, the equivalent total drag then increases. Thus, a minimum equivalent total drag coefficient $C_{D_t \min}$ occurs at an optimum total suction flow coefficient $C_{Q_{opt}}$.

The local drag coefficients $c_D(\varphi)$ as measured by the individual rakes are not shown. Their variation was the same as that of C_{D_w} , their magnitude was approximately $1/2$ that of C_{D_w} and their total deviation from the average was less than 10 percent in most cases.

L. W. Gross

NORTHROP CORPORATION
NORAIR DIVISION

11

CHECKER

REPORT NO.
NOR-63-46 (EBC-148)

DATE

MODEL

Figure 53 shows the variation of minimum equivalent total drag coefficient $C_{D_{t\min}}$ (including equivalent suction drag) and the corresponding optimum suction coefficient at minimum equivalent total drag $C_{Q_{opt}}$ with length Reynolds number R_L at angle of attack $\alpha = 0^\circ$. The values of $C_{D_{t\min}}$ and $C_{Q_{opt}}$ were determined from Figures 7 through 52. Also shown in Figure 53 are the coefficients $C_{D_{t\min}}$ and $C_{Q_{opt}}$ as determined in the Norair 7- by 10-foot wind tunnel and given in reference 1.

The lengthwise distributions of the nondimensional suction velocity v_0^* for equivalent area suction are shown in Figure 54 for several selected test numbers at 2 and 5 atmospheres wind tunnel pressure. At their respective Reynolds numbers, the chosen test point was that one closest to minimum equivalent total drag. For comparison, a suction distribution measured during the Norair test and the design suction distribution are also shown. The measured boundary layer velocity profiles corresponding to the suction velocity distributions of Figure 54 are given in Figures 55 through 61.

The variation of the boundary layer velocity profiles, as measured by the top boundary layer rake, with total suction flow coefficient C_Q is shown in Figures 62 through 68 for several test runs. The test runs are the same as those for which Figures 55 through 61 illustrate individual test points. Only the boundary layer profiles measured by the top rake are shown since those measured by the other rakes are similar.

ENGINEER	L. W. Gross	PAGE	12
CHECKER		REPORT NO.	
DATE		MODEL	

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L. W. Gross	NORTHROP CORPORATION NORAIR DIVISION	13
CHECKER		REPORT NO.
DATE		NOR-63-46 (RLC-140)
		MODEL

III. THEORETICAL STUDY

A. COMPUTATION PROCEDURE

The test points chosen for a detailed analysis of the boundary layer development are listed in Table IV and were those whose lengthwise distributions of nondimensional equivalent area suction velocity are shown in Figure 54. The test points were chosen to cover the complete range of Reynolds numbers and both of the wind tunnel pressures used. At their respective Reynolds numbers the chosen test points were those closest to minimum equivalent total drag.

Development of the boundary layer for the selected test points was calculated by means of Raetz's method (reference 10) on an IBM 7090 high speed digital computer. The method calculates boundary layer profiles at a large number of chordwise steps by a finite difference method. Numerical data defining the boundary conditions is required at each point. For computational stability, these data must be smooth and consistent, and their derivatives are restricted in magnitude so that the differences between points are not too large. For this reason, the input parameters are usually defined as analytic approximations to the given data.

Figure 69 is a comparison of the measured lengthwise velocity distribution and the approximation used for the calculations. The approximation is by a method developed by Goldsmith and can be used whenever it is not necessary that the approximation pass through the defining points (in this case the measured points). The degree of approximation can be

ENGINEER	L. W. GROSS	PAGE	14
CHECKER	NORTHROP CORPORATION NORAIR DIVISION	REPORT NO.	NOR-63-46 (BLG-148)
DATE		MODEL	

adjusted but in this case it was felt that the approximation was sufficiently close since it fell within the experimental accuracy of the points and the velocity gradients were properly defined. The nondimensional equivalent area suction velocity distribution, used for a given test point is illustrated, along with the measured test points, with the summary of results for that test point. They are shown in Figures 70, 73, 76, 79, 82, 85, and 88.

B. THEORETICAL RESULTS

The computed development of the laminar boundary layer for each of the test points studied is shown in Figures 70, 73, 76, 79, 82, 85 and 88. Shown is the Reynolds number based on the boundary layer momentum thickness $R_\theta = \frac{U_0}{g}$ and the shape parameter $H = \delta^*/\theta$, which is an indication of the boundary layer stability.

In Figures 71, 74, 77, 80, 83, 86 and 89 the theoretical boundary layer profiles at the boundary layer rake positions are compared with the boundary layer velocities as measured by the rake total pressure and static pressure tubes. Also included are the boundary layer parameters momentum thickness θ , displacement thickness δ^* , shape parameter H , momentum thickness Reynolds number R_θ and wake drag coefficient C_{Dw} , as determined from the calculated and measured velocities. The development of the boundary layer along the surface of the model is also illustrated by the boundary layer velocity profiles calculated at a number of axial stations and given in Figures 72a and b, 75a and b, 78a and b, 81a and b, 84a and b, 87a and b, and 90a and b.

ENGINEER L. W. GROS	ANALYST [REDACTED]	PAGE 15
CHECKER	NORTHROP CORPORATION MORAIR DIVISION	REPORT NO. NDR-63-46 (BLG-146)
DATE		MODEL

* IV DISCUSSION

At an angle of attack $\alpha = 0^\circ$ full length laminar flow was maintained on the Reichardt body of revolution with low drag suction up to a length Reynolds number $R_L = 57.8 \times 10^6$ (see Figure 53). The minimum equivalent total drag coefficient (based on wetted area and including equivalent suction drag) was $C_{Dt\min} = 2.65 \times 10^{-4}$ and the corresponding total suction coefficient was $C_{Q\text{opt}} = 1.77 \times 10^{-4}$.

According to Figure 53, the total suction coefficient for minimum equivalent total drag $C_{Q\text{opt}}$ decreases very slowly with increasing Reynolds number from approximately $C_{Q\text{opt}} = 2 \times 10^{-4}$ at $R_L = 15 \times 10^6$ to $C_{Q\text{opt}} = 1.77 \times 10^{-4}$ at $R_L = 57.8 \times 10^6$. This relatively slow decrease in C_Q with Reynolds number is to be expected because the boundary layer becomes more sensitive to disturbances at increasing Reynolds numbers, requiring increasing values of $C_{Q\text{opt}} / R_L$ to maintain full length laminar flow at higher length Reynolds numbers. The total equivalent drag then decreases with increasing Reynolds numbers at a considerably slower rate than the laminar friction drag of a flat plate.

However, the sudden increase of suction requirements, characteristic of tests of laminar suction models, as the disturbance level (due to turbulence and noise) of the wind tunnel increases beyond a certain level did not occur during the tests in the 12-foot pressure wind tunnel. (An example of this sudden increase in suction requirements can be seen in the Morair data of Figure 53.) This implies that the Reynolds number limit of the Ames wind tunnel was probably not reached during these tests.

ENGINEER	COLLEGE	PAGE
L. W. Gross	NORTHROP CORPORATION NORAIR DIVISION	16
CHECKER		REPORT NO.
DATE		MODEL

Limitations were rather caused by the appearance of a critical roughness but insufficient time was available to run the tunnel again after locating and removing the roughness.

At the low end of the Reynolds number range ($R_L \approx 17 \cdot 10^6$, see Figure 53) the equivalent total drag measured at Ames was higher, at the same Reynolds number, than that measured in the Norair wind tunnel. In Figure 54 are compared the lengthwise distributions of nondimensional equivalent area suction velocity v_0^* as measured in the two wind tunnels at approximately the same Reynolds number R_L . It can be seen that less suction aft of 85% of the body length was used in the Ames tests than in the Norair tests. According to reference 1 the equivalent total drag of the Reichardt body of revolution is very sensitive to the amount of suction in this area. On the basis of these results it appears that the total equivalent drags of the two cases would match more closely if, in the Ames tests, more suction had been used aft of 85% of the body length at the lower Reynolds numbers.

The calculated boundary layer velocity profiles at the aft end of the model show good agreement with the velocity profiles measured by the boundary layer rakes (Figure 71, 74, 77, 80, 83, 86 and 89). The agreement is especially good between the calculated profile and rakes numbered 1, 2, 3 and 4 which were located at radial angles (measured from the top of the model) $\varphi = 0^\circ, 30^\circ, 60^\circ$ and 270° respectively. Rakes 5 and 6, which were located at $\varphi = 225^\circ$ and 180° , have velocity profiles characteristic of the presence of turbulent bursts. This discrepancy suggests the possibility that the rear of the model may have been at a slight angle.

L. W. Gross	NORTHROP CORPORATION NORAIR DIVISION	17
CHECKER		REPORT NO.
DATE		NOR-63-46 (BLG-142)

of attack such that the bottom of the model was on the leeward side of the wind tunnel flow; although it was known from pressure measurements around the circumference at an axial station near the nose that the model was aligned with the flow in this region. The apparent angle of attack at the rear of the model may have been due to slight angularities of flow already present in the wind tunnel or induced by the mounting system. The slightly increased drag over the bottom of the model also may have been due to subcritical roughness or surface imperfections, but, since the drag increase was present to the same extent over a wide range of Reynolds numbers, roughness effects would not appear to be the reason.

The boundary layer development, as determined from the theoretical computations and presented in Figures 70, 73, 76, 82, 85 and 88, shows similar behavior in the seven cases studied. The momentum thickness Reynolds number increased gradually with length, while the shape parameter H was maintained at a value ranging from 2.4 to 2.3 until 81% of the body length had been traversed. Aft of 81% length the region of the rear pressure rise was starting and increased suction was required sufficient to restrain the growth of R_g to approximately its previous rate while H was dropping in value. The essentially constant rate of growth of R_g was maintained up to 90% length, at which time R_g had achieved a value that increased as length Reynolds number R_L increased and varied from $R_g = 2300$ at $R_L = 17.14 \times 10^6$ to $R_g = 3600$ at $R_L = 56.74 \times 10^6$.

In the region of the strong pressure rise from 90% length to the rear of the model, the momentum thickness Reynolds number R_g grew rapidly. The ultimate value of R_g again depended on length Reynolds number and varied from $R_g = 4500$ at $R_L = 17.14 \times 10^6$ to $R_g = 5500$ at $R_L = 56.74 \times 10^6$.

L. W. Gross	NORTHROP CORPORATION NORAIR DIVISION	18
CHIEFER		REPORT NO.
DATE		NOR-63-46 (BLG-148)

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L. W. Gross	NORTHROP CORPORATION NORAIR DIVISION	REPORT NO. NOR-63-46 (BLC-148)
CHECKER		MODEL
DATE		

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L. W. Gross	NORTHROP CORPORATION NORAIR DIVISION	20
CHECLER		REPORT NO.
DATE		NOR-63-46 (BLC-148) MODEL

LIST OF TABLES AND FIGURES

<u>Table No.</u>	<u>Table Title</u>
I	Model Coordinates
II	Characteristics of Model Slot and Metering Hole Design
III	Static Pressure Orifice and Microphone Locations of Model
IV	Test Points Studied for Theoretical Analysis of Experiments

<u>Figure No.</u>	<u>Figure Title</u>
1	Model Cross Section with Details of Suction Slots
2	Installation Drawing-- Reichardt Body of Revolution with Low Drag Suction in NASA-Ames 12-Foot Pressure Wind Tunnel
3	Reichardt Body of Revolution with Low Drag Suction In NASA-Ames 12-Foot Pressure Wind Tunnel
4	Coordinate System
5	Comparison of Measured and Theoretical Velocity Distributions
6	Design Suction Velocity Distribution and Boundary Layer Development
7-52	Drag C_D Versus Suction Quantity C_{Q_t} for Various Reynolds Numbers R_L and Angles of Attack
53	Variation of Minimum Total Drag $C_{D_t}^{\min}$ and Suction Coefficient at Minimum Total Drag $C_{Q_{opt}}$ with Length Reynolds Number R_L
54	Lengthwise Distribution of Equivalent Distributed Suction Velocity v_0^* for Several Reynolds Numbers R_L
55-61	Boundary Layer Velocity Profiles as Measured at the Aft End of the Model
62-68	Variation of Aft End Boundary Layer Velocity Profile with Suction Coefficient C_{Q_t}
69.	Comparison of Assumed lengthwise Velocity Distribution used for Theoretical Calculations and Measured Test Points

L. W. GROSS

NORTHROP CORPORATION
NORAIR DIVISION

REPORT NO.
NOR-63-46- (B.I.C.-148)

CHECKER
DATE

MODEL

Figure No.

Figure Title

- 70 Nondimensional Equivalent Distributed Suction Velocity Distribution and Boundary Layer Development for Test Point No. 2
- 71 Comparison of Calculated and Measured Boundary Layer Velocity Profiles at Rear End of Body for the Conditions of Test Point No. 2
- 72a, b Calculated Boundary Layer Profiles at Various Lengthwise Positions s/L for the Conditions of Test Point No. 2
- 73 Nondimensional Equivalent Distributed Suction Velocity Distribution and Boundary Layer Development for Test Point No. 102
- 74 Comparison of Calculated and Measured Boundary Layer Velocity Profiles at Rear End of Body for the Conditions of Test Point No. 102
- 75a, b Calculated Boundary Layer Profiles at Various Lengthwise Positions s/L for the Conditions of Test Point No. 102
- 76 Nondimensional Equivalent Distributed Suction Velocity Distribution and Boundary Layer Development for Test Point No. 47
- 77 Comparison of Calculated and Measured Boundary Layer Velocity Profiles at Rear End of Body for the Conditions of Test Point 47
- 78a, b Calculated Boundary Layer Profiles at Various Lengthwise Positions s/L for the Conditions of Test Point No. 47
- 79 Nondimensional Equivalent Distributed Suction Velocity Distribution and Boundary Layer Development for Test Point No. 117
- 80 Comparison of Calculated and Measured Boundary Layer Velocity Profiles at Rear End of Body for the Conditions of Test Point No. 117
- 81a, b Calculated Boundary Layer Profiles at Various Lengthwise Positions s/L for the Conditions of Test Point No. 117
- 82 Nondimensional Equivalent Distributed Suction Velocity Distribution and Boundary Layer Development for Test Point No. 262

CHECKER	
F.Y.F.	

NORAIR DIVISION

REPORT NO.
NOR-63-46 (BLC-143)
MODEL

Figure No.Figure Title

- 83 Comparison of Calculated and Measured Boundary Layer Velocity Profiles at Rear End of Body for the Conditions of Test Point No. 262
- 84a, b Calculated Boundary Layer Profiles at Various Lengthwise Positions s/L for the Conditions of Test Point No. 262
- 85 Nondimensional Equivalent Distributed Suction Velocity Distribution and Boundary Layer Development for Test Point No. 268
- 86 Comparison of Calculated and Measured Boundary Layer Velocity Profiles at Rear End of Body for the Conditions of Test Point No. 268
- 87a, b Calculated Boundary Layer Profiles at Various Lengthwise Positions s/l. for the Conditions of Test Point No. 268
- 88 Nondimensional Equivalent Distributed Suction Velocity Distribution and Boundary Layer Development for Test Point No. 287
- 89 Comparison of Calculated and Measured Boundary Layer Velocity Profiles at Rear End of Body for the Conditions of Test Point No. 287
- 90a, b Calculated Boundary Layer Profiles at Various Lengthwise Positions s/L for the Conditions of Test Point No. 287

NORTHROP CORPORATION
NORAIR DIVISION

REPORT NO.

NOR 63-77 (BIC-148)

M351

CHECKER

DATE

July 1963

TABLE IMODEL COORDINATES

<u>X/L</u>	<u>Z/L</u>
0	0
.01	.0163
.03	.0255
.05	.0313
.07	.0357
.10	.0408
.15	.0472
.20	.0519
.25	.0554
.30	.0581
.35	.0601
.40	.0614
.45	.0622
.50	.0625
.55	.0622
.60	.0614
.65	.0601
.70	.0581
.75	.0554
.80	.0519
.85	.0472
.90	.0408
.95	.0313
1.00	.0231
1.03	.0226

TABLE II
CHARACTERISTICS OF MODEL SLOT AND METERING HOLE DESIGN

All slot widths = 0.003 inch

Chamber Number	Slot Number	Slot Position (% length)	Hole Diameter (inch)	Number of Holes (per inch)	Chamber Number	Slot Number	Slot Position (% length)	Hole Diameter (inch)	Number of Holes (per inch)
1	1	2.778	0.0260	11.546	6	29	41.667	0.0465	4.160
	2	4.167	0.0260	12.393		30	43.056	0.0400	4.465
	3	5.556	0.0350	11.277		31	44.444	0.0360	4.861
1	4	6.944	0.0465	8.201	6	32	45.833	0.0330	5.221
	5	8.333	0.0465	7.934		33	47.222	0.0300	5.186
2	6	9.722	0.0400	8.827	6	34	48.611	0.0310	5.365
	7	11.111	0.0350	9.711		35	50.000	0.0292	5.365
	8	12.500	0.0310	10.559		36	51.389	0.0292	5.365
	9	13.889	0.0280	11.378		37	52.778	0.0330	4.721
	10	15.278	0.0465	6.920		38	54.167		4.753
	11	16.667	0.0350	8.673		39	55.556		4.753
	12	18.056	0.0310	9.550		40	56.944		4.691
3	13	19.444	0.0280	10.197	6	41	58.333		4.713
	14	20.833	0.0260	10.597		42	59.722		4.734
	15	22.222	0.0260	9.338		43	61.111		4.762
	16	23.611	0.0465	5.810		44	62.500		4.795
4	17	25.000	0.0370	6.975	7	45	63.889		4.835
	18	26.389	0.0330	7.705		46	65.278		4.868
	19	27.778	0.0292	8.313		47	66.667		4.688
4	20	29.167	0.0280	8.540	7	48	68.056		4.738
	21	30.556	0.0260	8.873		49	69.444		4.726
5	22	31.944	0.0465	4.968	8	50	70.833		4.698
	23	33.333	0.0370	5.898		51	72.222		4.763
	24	34.722	0.0330	6.441		52	73.611		4.734
	25	36.111	0.0310	6.694		53	75.000		4.711
	26	37.500	0.0292	7.008		54	76.389		4.792
5	27	38.889	0.0280	7.143	8	55	77.778		4.675
	28	40.278	0.0260	7.283		56	79.167	0.0330	4.738

TABLE II (continued)

<u>Chamber Number</u>	<u>Slot Number</u>	<u>Slot Position (% length)</u>	<u>Hole Diameter (inch)</u>	<u>Number of Holes (per inch)</u>	<u>Chamber Number</u>	<u>Slot Number</u>	<u>Slot Position (% length)</u>	<u>Hole Diameter (inch)</u>	<u>Number of Holes (per inch)</u>
9	57	80.035	0.0260	3.026	11	88	90.799	0.0292	6.200
	58	80.382		3.304		89	91.146	0.0260	7.028
	59	80.729		3.674		90	91.493		6.544
	60	81.076	0.0260	4.071		91	91.840		6.197
	61	81.424	0.0280	3.985		92	92.187		5.837
	62	81.771	0.0260	4.099		93	92.535		5.621
	63	82.118		4.035		94	92.882	0.0260	5.399
	64	82.465		4.059		95	93.229	0.0465	4.538
	65	82.812		4.085		96	93.576	0.0380	5.633
	66	83.160		3.938		97	93.924	0.0320	6.775
	67	83.507		3.922		98	94.271	0.0292	7.623
	68	83.854		3.811		99	94.618	0.0280	8.336
	69	84.201		3.653		100	94.965	0.0260	8.536
	70	84.549		3.540		101	95.312		8.042
	71	84.896		3.520		102	95.660		7.634
	72	85.243		3.452	12	103	96.007	0.0260	7.364
	73	85.590	0.0260	3.382		104	96.354	0.0465	5.446
10	74	85.937	0.0390	4.007	13	105	96.701	0.0400	6.379
	75	86.285	0.0350	3.948		106	96.049	0.0360	7.140
	76	86.632	0.0330	3.888		107	97.396	0.0320	8.147
	77	86.979	0.0292	4.330		108	97.743	0.0310	8.760
	78	87.326	0.0280	4.833		109	98.090	0.0280	9.624
	79	87.674	0.0260	5.140		110	98.437	0.0260	10.526
	80	88.021		4.882		111	98.785		9.363
	81	88.368		4.724		112	99.132		8.625
	82	88.715		4.377	13	113	99.479	0.0260	8.096
	83	89.062		4.290					
10	84	89.410	0.0260	4.120					
11	85	89.757	0.0420	3.970					
	86	90.104	0.0370	4.589					
11	87	90.451	0.0320	5.396					

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DATE

July 1963

NORTHROP CORPORATION
NORAIR DIVISION

22d

REPORT NO.

NOR 63-46 (BLC-148)

MODEL

TABLE III
STATIC PRESSURE ORIFICE AND MICROPHONE
LOCATIONS OF LAMINAR SUCTION MODEL

<u>Static Orifice Number</u>	<u>Position (% length)</u>	<u>Microphone Number</u>	<u>Position (% length)</u>
1	2.00	1	12.847
2a, b, c, d	3.00	2	30.903
3	5.00	3	50.694
4	7.50	4	63.194
5	10.00	5	78.125
6	15.00	6	84.375
7	20.00	7	88.542
8	25.50	8	92.361
9	30.00	9	97.222
10	35.00		
11	40.00		
12	45.00		
13	55.00		
14	60.00		
15	65.00		
16	70.00		
17	75.25		
18	80.00		
19	85.00		
20	90.00		
21	95.00		

CHECKER
DATE
July 1963

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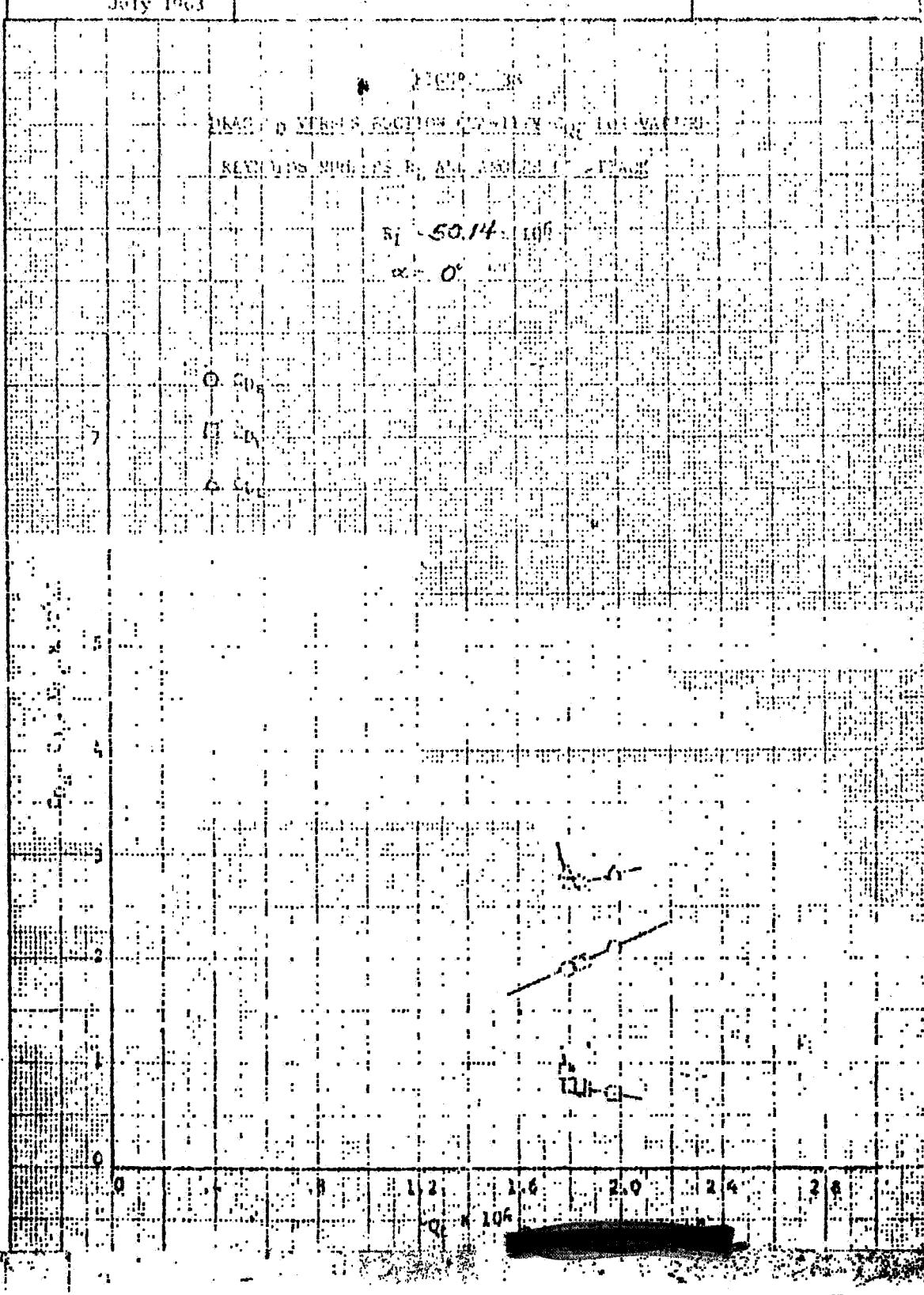
REPORT NO.
NOR 63-46 (BLC-146)
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TABLE IV

TEST POINTS STUDIED FOR THEORETICAL ANALYSIS OF EXPERIMENTS

Run No.	R _L	Wind Tunnel Pressure (Atmospheres)	C _{Q_t} × 10 ⁴	C _{Q_t} /C _{Q_{opt}}
2	17.136	1	2.050	
102	22.166	1	1.979	1.041
47	30.228	4	1.696	.974
117	30.449	1	2.007	1.014
262	38.036	4	1.860	.979
268	46.050	4	1.818	.977
287	56.740	4	1.789	.988

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July 1963		



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DRAG OF VERTICALLY SUGGED QUADRATIC AIRFOILS

REYNOLDS NUMBERS R, AND ANGLES OF ATTACK

50.68 x 10⁶

0°

C. COE

CL

CD

CL'

CD'

CL''

CD''

CL'''

CD'''

CL''''

CD''''

CL'''''

CD'''''

CL''''''

CD''''''

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62

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FLR 63-46 (BLU-15)
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DATE

July 1963

FIGURE 42

DRAG CD VERSUS SECTION REYNOLDS NUMBER FOR VARIOUS

REYNOLDS NUMBER AND ANGLES OF ATTACK

5096

0°

C_D

0.0

0.1

0.2

0.3

0.4

0.5

0.6

0.7

0.8

0.9

1.0

1.1

1.2

1.3

1.4

1.5

1.6

1.7

1.8

1.9

2.0

2.1

2.2

2.3

2.4

2.5

2.6

2.7

2.8

2.9

3.0

3.1

3.2

3.3

3.4

3.5

3.6

3.7

3.8

3.9

4.0

4.1

4.2

4.3

4.4

4.5

4.6

4.7

4.8

4.9

5.0

5.1

5.2

5.3

5.4

5.5

5.6

5.7

5.8

5.9

6.0

6.1

6.2

6.3

6.4

6.5

6.6

6.7

6.8

6.9

7.0

7.1

7.2

7.3

7.4

7.5

7.6

7.7

7.8

7.9

8.0

8.1

8.2

8.3

8.4

8.5

8.6

8.7

8.8

8.9

9.0

9.1

9.2

9.3

9.4

9.5

9.6

9.7

9.8

9.9

10.0

10.1

10.2

10.3

10.4

10.5

10.6

10.7

10.8

10.9

11.0

11.1

11.2

11.3

11.4

11.5

11.6

11.7

11.8

11.9

12.0

12.1

12.2

12.3

12.4

12.5

12.6

12.7

12.8

12.9

13.0

13.1

13.2

13.3

13.4

13.5

13.6

13.7

13.8

13.9

14.0

14.1

14.2

14.3

14.4

14.5

14.6

14.7

14.8

14.9

15.0

15.1

15.2

15.3

15.4

15.5

15.6

15.7

15.8

15.9

16.0

16.1

16.2

16.3

16.4

16.5

16.6

16.7

16.8

16.9

17.0

17.1

17.2

17.3

17.4

17.5

17.6

17.7

17.8

17.9

18.0

18.1

18.2

18.3

18.4

18.5

18.6

18.7

18.8

18.9

19.0

19.1

19.2

19.3

19.4

19.5

19.6

19.7

19.8

19.9

20.0

20.1

20.2

20.3

20.4

20.5

20.6

20.7

20.8

20.9

21.0

21.1

21.2

21.3

21.4

21.5

21.6

21.7

21.8

21.9

22.0

22.1

22.2

22.3

22.4

22.5

22.6

22.7

22.8

22.9

23.0

23.1

23.2

23.3

23.4

23.5

23.6

23.7

23.8

23.9

24.0

24.1

24.2

24.3

24.4

24.5

24.6

24.7

24.8

24.9

25.0

25.1

25.2

25.3

25.4

25.5

25.6

25.7

25.8

25.9

26.0

26.1

26.2

26.3

26.4

26.5

26.6

26.7

26.8

26.9

27.0

27.1

27.2

27.3

27.4

27.5

27.6

27.7

27.8

27.9

28.0

28.1

NORTHROP CORPORATION
NORAIR DIVISION

NOE 62-46 (BLIC-14)

ENGINEER
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MECHANIC

DATE July 1963

DRAG ON VARIOUS SURFACE GEOMETRIES FOR VARIOUS
LEWISIA STRENGTHS AND ANGLES OF ATTACK

R₁ = 51.04 mm

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1963ENGINEER
L. W. GROSS
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AEROSPACE DIVISIONPAGE
64
REPORT NO.
NOR 63-46 (BLG-140)DATE
July 1963

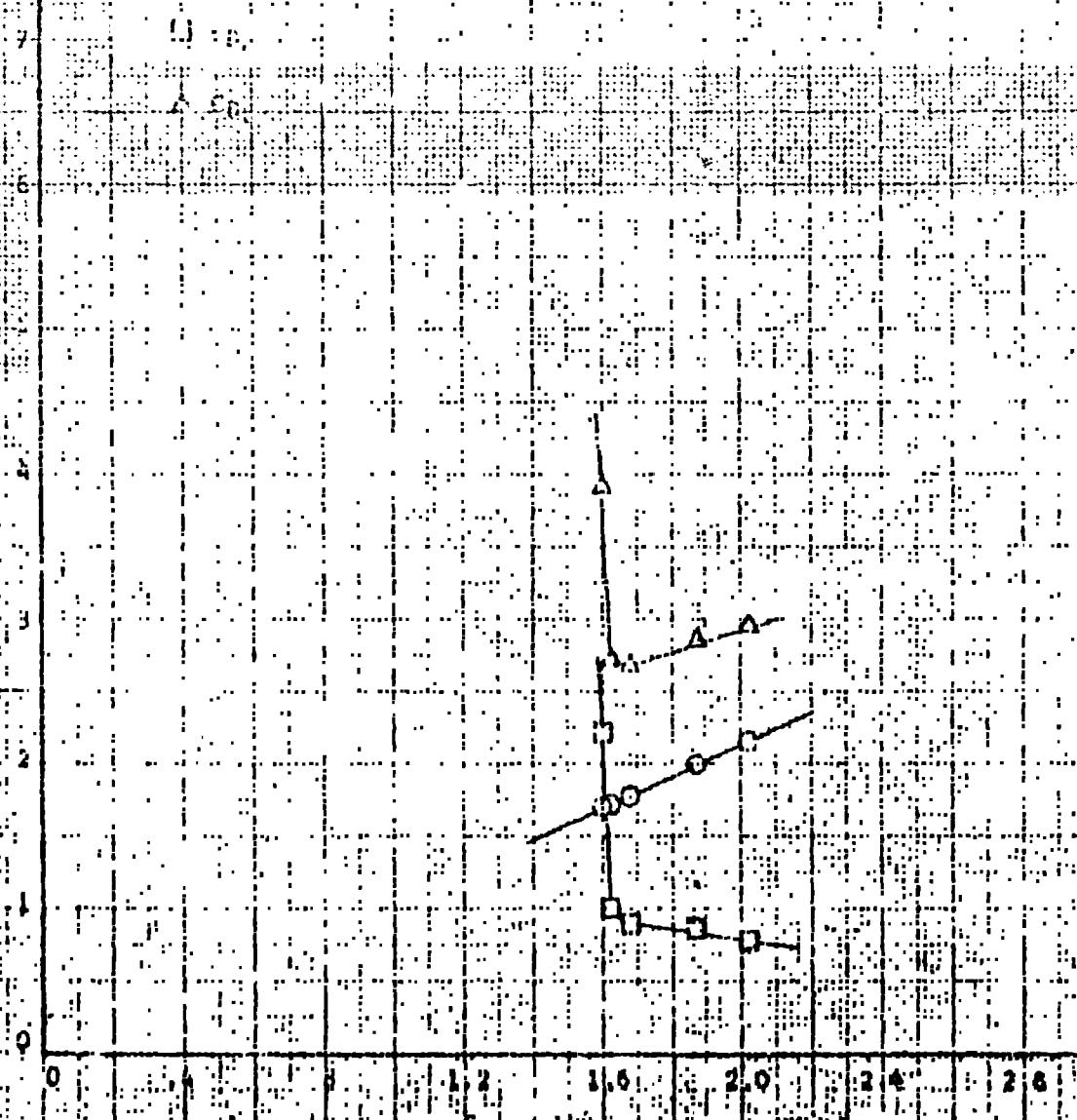
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FIGURE 42

DRAG C_D VERSUS SECTION QUANTITY L_1 FOR $\alpha = 0^\circ$ REYNOLDS NUMBERS R_1 AND ANGLES OF ATTACK

$$R_1 = 51,070$$

$$\alpha = 0^\circ$$

 C_D 

ENG. TECH	L. W. Gross CHIEFER	NORTHROP CORPORATION NORAIR DIVISION	PAGE 65
DATE	July 1963	REPORT NO. NOR 63-46 (M-0-1487) MODEL	

FIGURE 43.

DFAG CO. VERSUS SUCTION QUANTITY Q FOR VARIOUS
REYNOLDS NUMBERS R, AND ANGLES OF ATTACK

$$R_L = 51.12 \times 10^5$$

$$\alpha = 0^\circ$$

O C0

D 40

A 50

B 60

C 70

D 80

E 90

F 100

G 110

H 120

I 130

J 140

K 150

L 160

M 170

Q = 10%

C0 = 10%

C1 = 10%

C2 = 10%

C3 = 10%

C4 = 10%

C5 = 10%

C6 = 10%

C7 = 10%

C8 = 10%

C9 = 10%

C10 = 10%

C11 = 10%

C12 = 10%

C13 = 10%

C14 = 10%

C15 = 10%

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C261 = 10%

C262 = 10%

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C267 = 10%

C268 = 10%

C269 = 1

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FIGURE 44

DRAG CO VERSUS SURFACE QUANTITY FOR VARIOUS

REYNOLDS NUMBERS R₁ AND ANGLES OF ATT.

R₁ = 51,621

$\alpha = 0^\circ$

O C_D

□ C_D

△ C_D

0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80 0.85 0.90 0.95 1.00 1.05 1.10 1.15 1.20 1.25 1.30 1.35 1.40 1.45 1.50 1.55 1.60 1.65 1.70 1.75 1.80 1.85 1.90 1.95 2.00 2.05 2.10 2.15 2.20 2.25 2.30 2.35 2.40 2.45 2.50 2.55 2.60 2.65 2.70 2.75 2.80 2.85 2.90 2.95 3.00 3.05 3.10 3.15 3.20 3.25 3.30 3.35 3.40 3.45 3.50 3.55 3.60 3.65 3.70 3.75 3.80 3.85 3.90 3.95 4.00 4.05 4.10 4.15 4.20 4.25 4.30 4.35 4.40 4.45 4.50 4.55 4.60 4.65 4.70 4.75 4.80 4.85 4.90 4.95 5.00 5.05 5.10 5.15 5.20 5.25 5.30 5.35 5.40 5.45 5.50 5.55 5.60 5.65 5.70 5.75 5.80 5.85 5.90 5.95 6.00 6.05 6.10 6.15 6.20 6.25 6.30 6.35 6.40 6.45 6.50 6.55 6.60 6.65 6.70 6.75 6.80 6.85 6.90 6.95 7.00 7.05 7.10 7.15 7.20 7.25 7.30 7.35 7.40 7.45 7.50 7.55 7.60 7.65 7.70 7.75 7.80 7.85 7.90 7.95 8.00 8.05 8.10 8.15 8.20 8.25 8.30 8.35 8.40 8.45 8.50 8.55 8.60 8.65 8.70 8.75 8.80 8.85 8.90 8.95 9.00 9.05 9.10 9.15 9.20 9.25 9.30 9.35 9.40 9.45 9.50 9.55 9.60 9.65 9.70 9.75 9.80 9.85 9.90 9.95 10.00

0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80 0.85 0.90 0.95 1.00 1.05 1.10 1.15 1.20 1.25 1.30 1.35 1.40 1.45 1.50 1.55 1.60 1.65 1.70 1.75 1.80 1.85 1.90 1.95 2.00 2.05 2.10 2.15 2.20 2.25 2.30 2.35 2.40 2.45 2.50 2.55 2.60 2.65 2.70 2.75 2.80 2.85 2.90 2.95 3.00 3.05 3.10 3.15 3.20 3.25 3.30 3.35 3.40 3.45 3.50 3.55 3.60 3.65 3.70 3.75 3.80 3.85 3.90 3.95 4.00 4.05 4.10 4.15 4.20 4.25 4.30 4.35 4.40 4.45 4.50 4.55 4.60 4.65 4.70 4.75 4.80 4.85 4.90 4.95 5.00 5.05 5.10 5.15 5.20 5.25 5.30 5.35 5.40 5.45 5.50 5.55 5.60 5.65 5.70 5.75 5.80 5.85 5.90 5.95 6.00 6.05 6.10 6.15 6.20 6.25 6.30 6.35 6.40 6.45 6.50 6.55 6.60 6.65 6.70 6.75 6.80 6.85 6.90 6.95 7.00 7.05 7.10 7.15 7.20 7.25 7.30 7.35 7.40 7.45 7.50 7.55 7.60 7.65 7.70 7.75 7.80 7.85 7.90 7.95 8.00 8.05 8.10 8.15 8.20 8.25 8.30 8.35 8.40 8.45 8.50 8.55 8.60 8.65 8.70 8.75 8.80 8.85 8.90 8.95 9.00 9.05 9.10 9.15 9.20 9.25 9.30 9.35 9.40 9.45 9.50 9.55 9.60 9.65 9.70 9.75 9.80 9.85 9.90 9.95 10.00

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FIGURE 34

DRAG CO VERSUS SURFACE QUALITY FOR VARIOUS
REYNOLDS NUMBERS R_L AND ANGLES OF ATTACK $R_L = 51,62 \times 10^6$ $\alpha = 0^\circ$ C_DC_DC_DC_DC_DC_DC_DC_DC_DC_DC_DC_DC_DC_DC_DC_DC_D

2

3

4

5

6

7

C_D

W 105

WILKINS

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FIGURE 25

DRAG COEFFICIENTS FOR VARIOUS

REYNOLDS NUMBERS R AND ANGLES OF ATTACK

R = 5480, TOF

 $\alpha = 0^\circ$ C_D
C_L
C_M

5

10

15

20

25

30

35

40

45

50

55

60

1.2 1.6 2.0 2.4 2.8

1.0

1.5

2.0

2.5

3.0

3.5

4.0

4.5

5.0

5.5

6.0

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147.0

147.5

148.0

ENGINEER
L. W. Gross
CHIEF

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69

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FIGURE 6.1

DRAG CO VERSUS INCLINATION ANGLE FOR VARIOUS

REYNOLDS NUMBERS R, AND ANGLES OF ATTACK

Re = 5488

$\alpha = 0^\circ$

O C_D

D S_D

A C_D

6

5

4

3

2

1

0

-1

-2

-3

-4

-5

-6

-7

-8

-9

-10

10⁴

12

14

16

18

20

22

24

26

10⁴

12

14

16

18

20

22

24

26

10⁴ 12 14 16 18 20 22 24 26

CHARTER

L. W. Gross

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— 5 —

73

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Introducing the new

三

DATE

July 1953

FIGURE 11

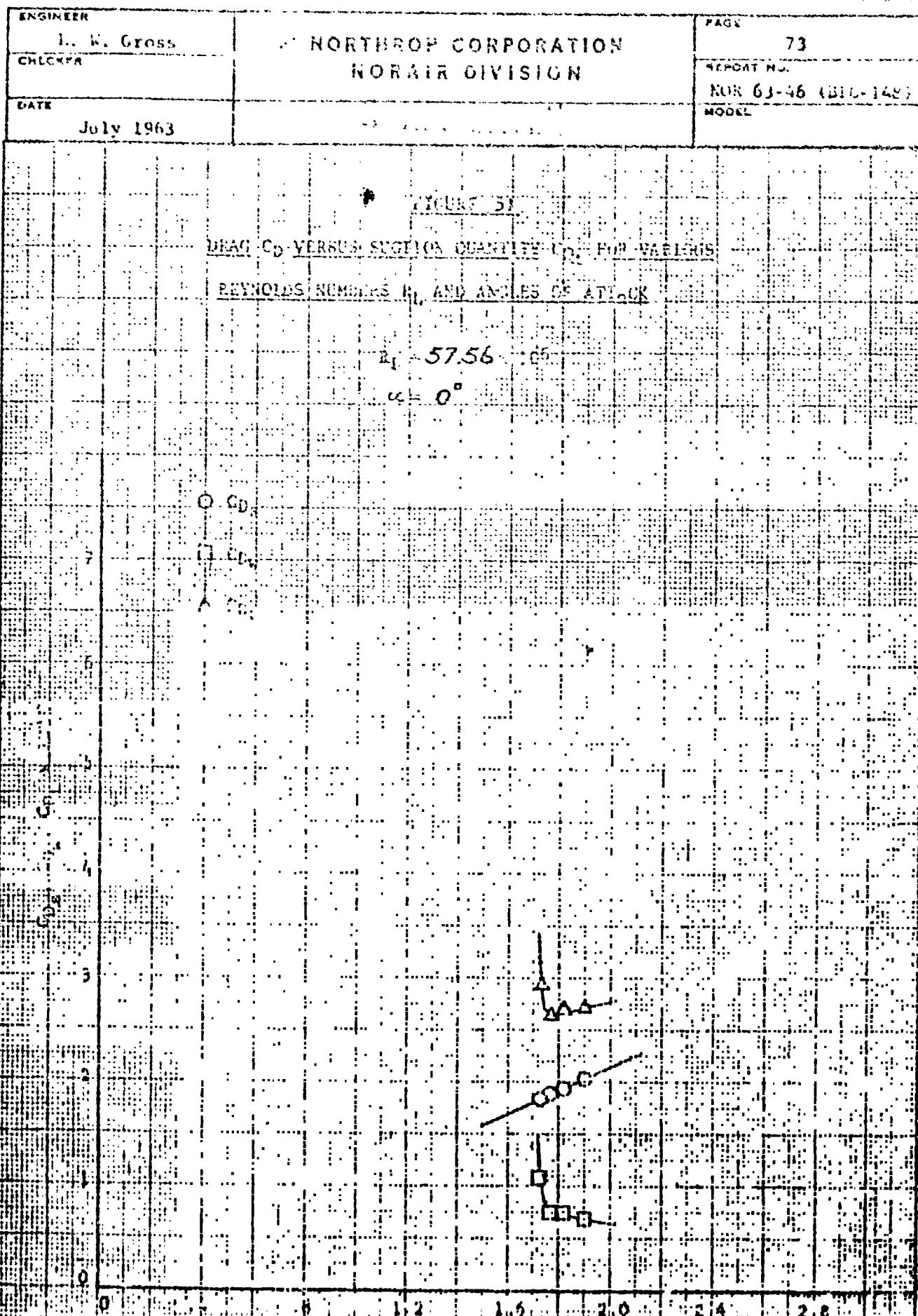
DRAG COEFFICIENTS VERSUS SECTION QUANTITY FOR THE VARIOUS

SEXUALIS HUMANS B. APP. ANGLO. THE RACE

56.80 195

$\alpha = 0^\circ$





ENGINEER
L. W. Gross

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PAGE

74

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FIGURE 54

DRAG C_D VERSUS FRICTION COEFFICIENT FOR VARIOUS
REYNOLDS NUMBERS R_L AND ANGLES OF ATTACK

$R_L = 57.76 \times 10^6$

$\alpha = 0^\circ$

C_D

A_u



0

1.2

1.6

2.0

2.4

2.8

C_D vs A_u

ENGINEER L. W. Gross
CHECKER
DATE July 1963

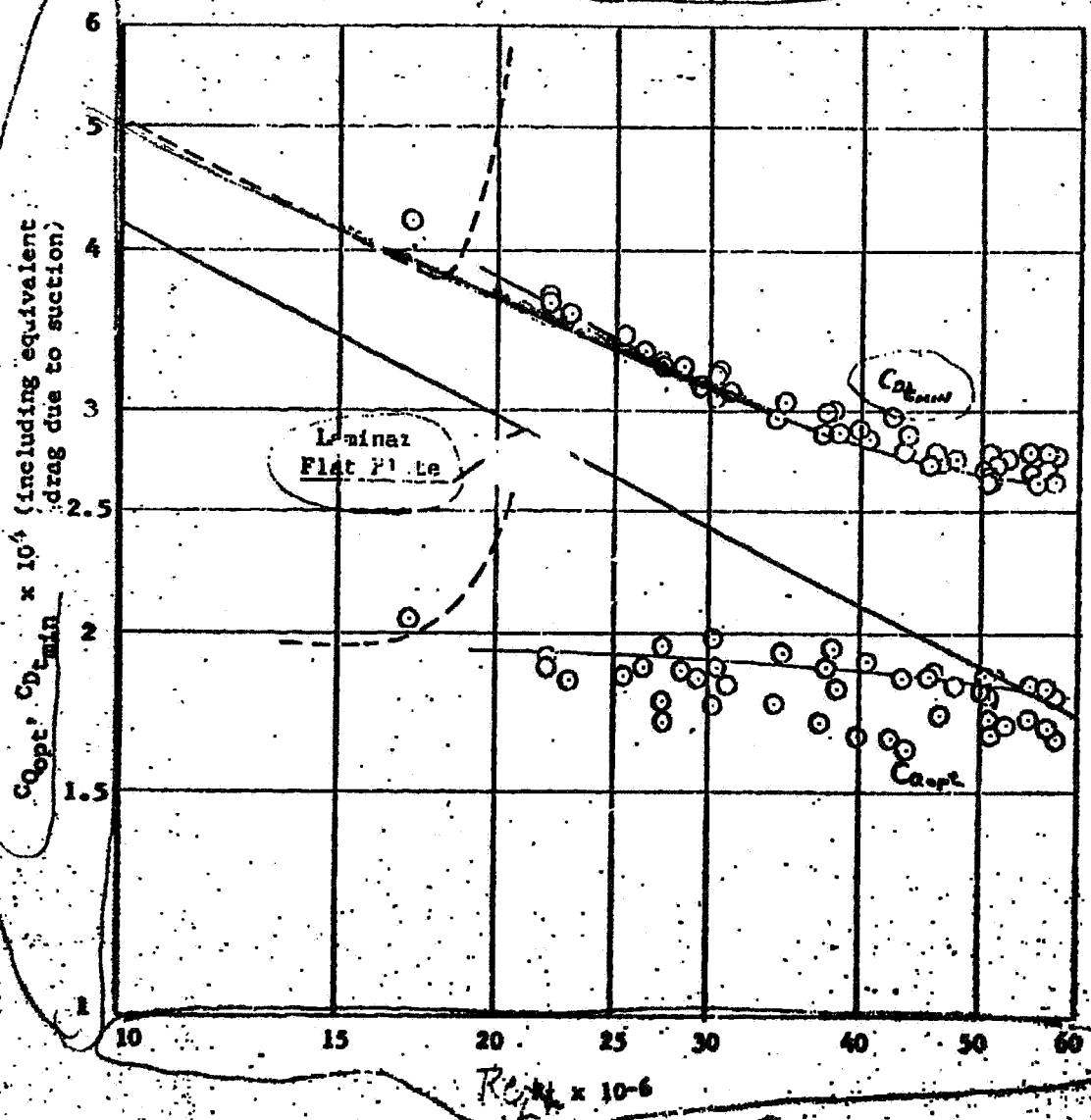
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(FIGURE 53) White

FIG. VARIATION OF MINIMUM TOTAL DRAG $C_{D,\text{min}}$ AND
SUCTION COEFFICIENT AT MINIMUM TOTAL DRAG $C_{Q,\text{opt}}$
WITH LENGTH REYNOLDS NUMBER R_L , $\alpha = 0^\circ$

NASA Ames Data
Norair Data (Ref. 1)



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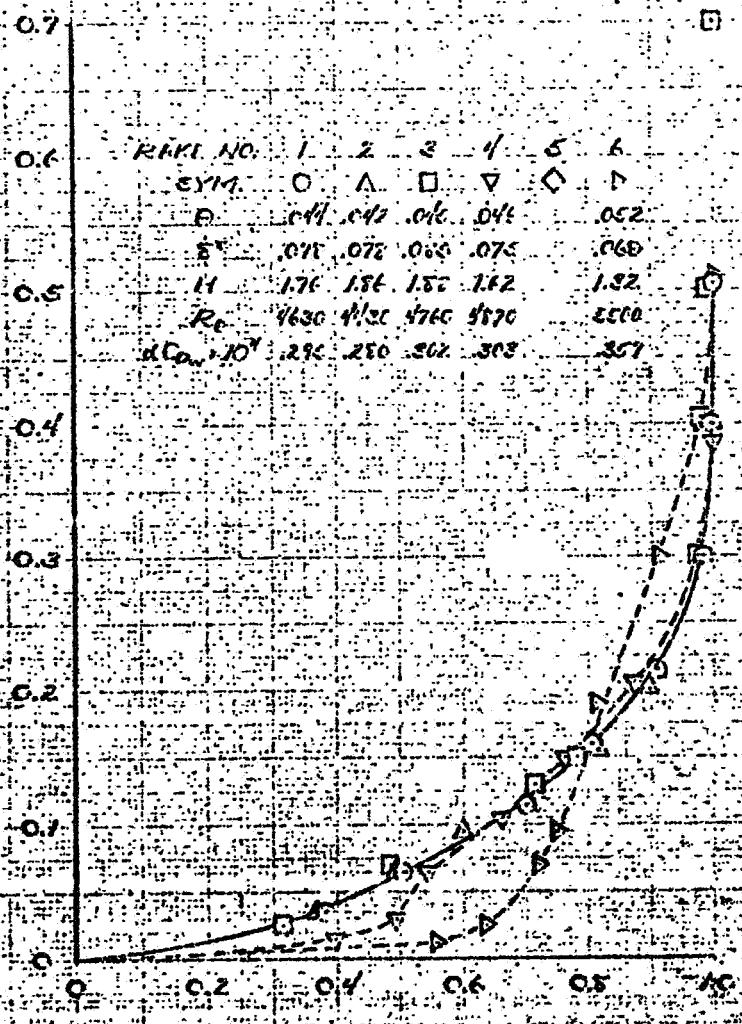
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FIGURE 55
BOUNDARY LAYER VELOCITY PROFILES AS MEASURED
AT THE AFT END OF THE MODEL

Run No. 2

$$R_L = 17.136 \times 10^6$$

$$C_{Q_t} = 2.050 \times 10^{-4}$$



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REPORT NO.

NOR 63-46 (BLC-148)

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DATE

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FIGURE 56BOUNDARY LAYER VELOCITY PROFILES AS MEASUREDAT THE AFT END OF THE MODEL

Run No. 102

$$R_L = 22,166 \times 10^6$$

$$C_{Q_L} = 1.979 \times 10^{-4}$$

0.7

0.6

0.5

0.4

y - IN.

0.3

0.2

0.1

	RAKE NO.	1	2	3	4	5	6
SYM	O	A	□	▽	△	▷	
C	0.51	0.23	0.36	0.35	0.35	0.37	
δ^+	0.56	0.53	0.62	0.65	0.65	0.67	
H	1.15	1.67	1.72	1.75	1.56	1.57	
R_b	6610	4430	1620	670	1730	5660	
$2C_{Q_L} \cdot 10^4$	2.30	2.20	2.42	2.51	2.36	2.19	

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79	REPORT NO.
	NOR 63-46 (BLG-148)
	MODEL

FIGURE 57

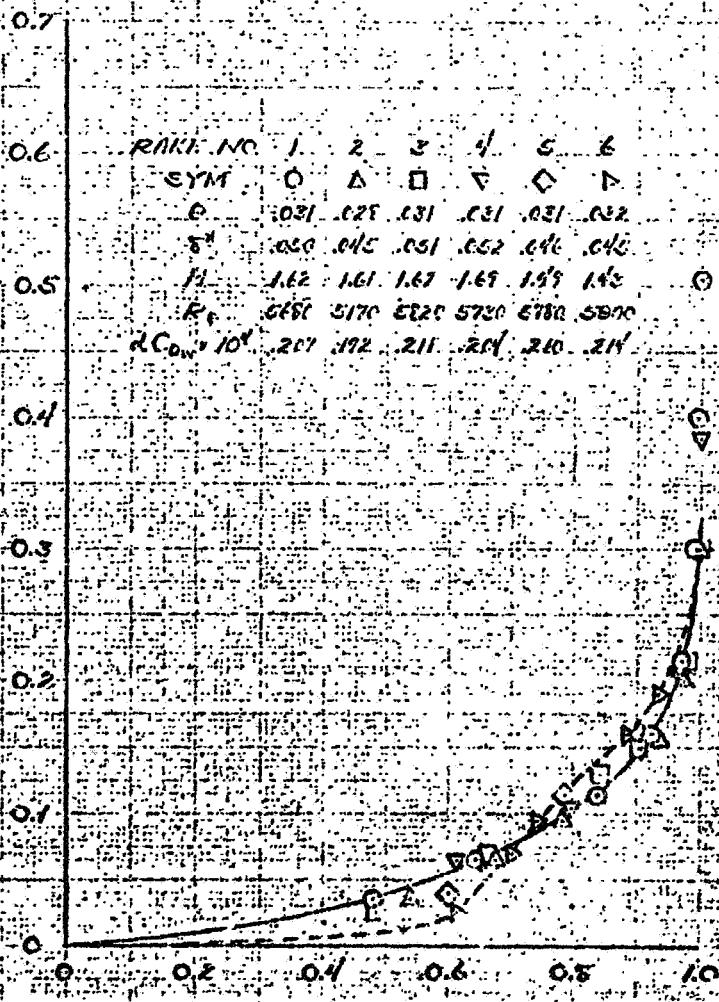
BOUNDARY LAYER VELOCITY PROFILES AS MEASURED

AT THE AFT END OF THE MODEL

Run No. 47

$$R_L = 30.238 \times 10^6$$

$$C_{Qe} = 1.696 \times 10^{-4}$$



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FIGURE 58
BOUNDARY LAYER VELOCITY PROFILES AS MEASURED
AT THE AFT END OF THE MODEL

Run No. 117
 $R_L = 30.449 \times 10^6$
 $= 2.007 \times 10^{-4}$

0.7

0.6

0.5

0.4

y = IN.

0.3

0.2

0.1

0

RAISE NO 1 2 3 4 5 6
 SYM O A □ V △ ▽
 C 0.24 0.23 0.26 0.28 0.25 0.25
 S 0.36 0.23 0.35 0.28 0.35 0.37
 H 1.41 1.43 1.52 1.52 1.42 1.42
 K₀ 4450 4310 4610 5230 4610 4610
 AC₀ 10⁴ 162 160 164 167 166 171

0.2 0.4 0.6 0.8 1.0

4/4

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FIGURE 59

BOUNDARY LAYER VELOCITY PROFILES AS MEASURED

AT THE AFT END OF THE MODEL

Run No. 262

$$R_L = 38.036 \times 10^6$$

$$C_{Qe} = 1.860 \times 10^{-4}$$

0.7

0.6

0.5

0.4

0.3

0.2

0.1

0

	RAKE NO.	1	2	3	4	5	6
SYM	O	Δ	□	◇	▲	◆	
C	0.15	0.20	0.24	0.28	0.31	0.39	
E	0.32	0.25	0.36	0.42	0.42	0.40	
H	1.58	1.46	1.49	1.46	1.36	1.26	
R _e	5800	5720	5620	6690	7150	6720	
dC _{Qe} /10 ⁴	1.15	1.20	1.61	1.02	2.05	2.07	

y/m

0.0 0.2 0.4 0.6 0.8 1.0

4/2

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FIGURE 60
BOUNDARY LAYER VELOCITY PROFILES AS MEASURED
AT THE AFT END OF THE MODEL

Run No. 268
 $R_L = 46.050 \times 10^6$
 $C_{Qc} = 1.818 \times 10^{-4}$

0.7

	RAKE NO.	1	2	3	4	5	6
SYM	O	A	□	▽	◇	△	
G	0R	022		022	020	021	
S*		027	028		022	025	
H	142	132		142	132	140	
Re	5330	6430		6270	6150	5510	
$(C_{Qc} \times 10^4)$	128	157		148	138	112	

0.6

Y = 111

0.5

0.4

0.3

0.2

0 0.2 0.4 0.6 0.8 1.0

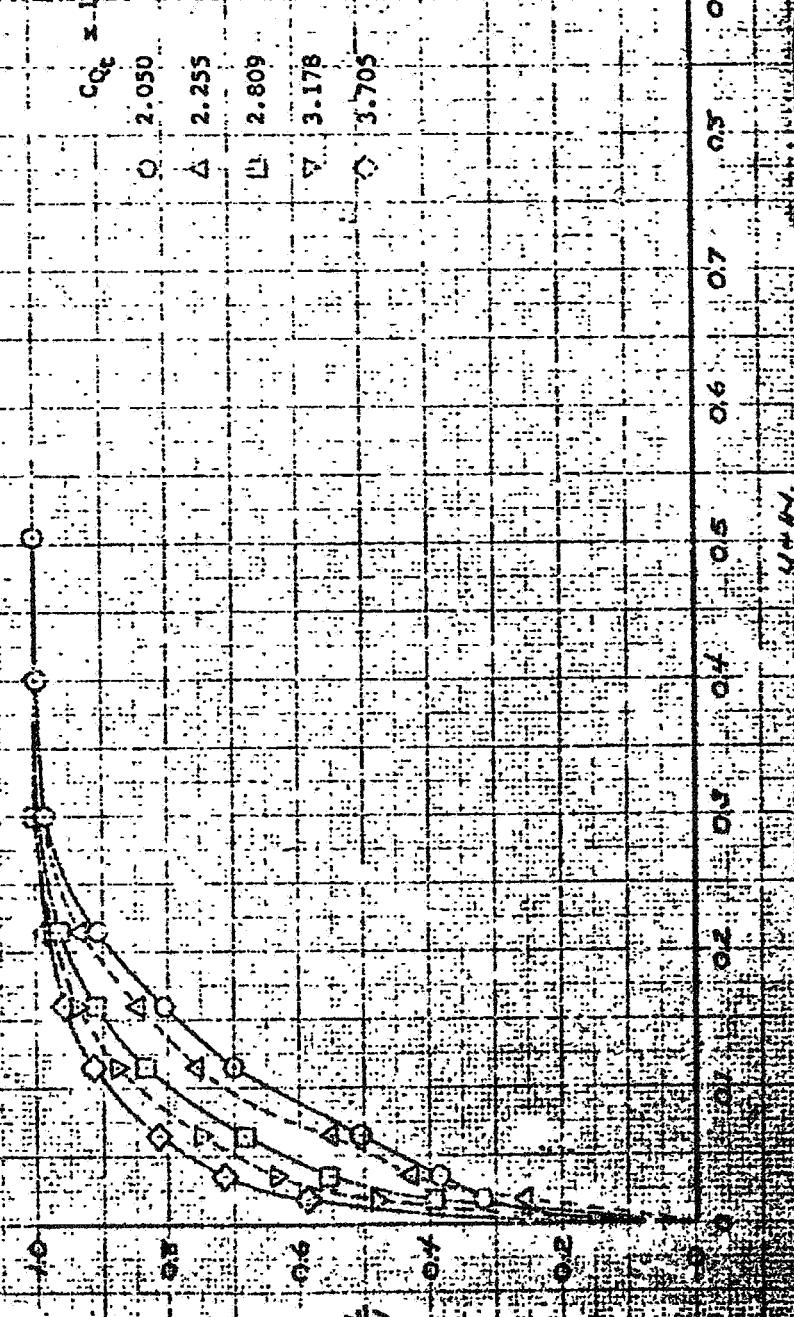
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MODEL

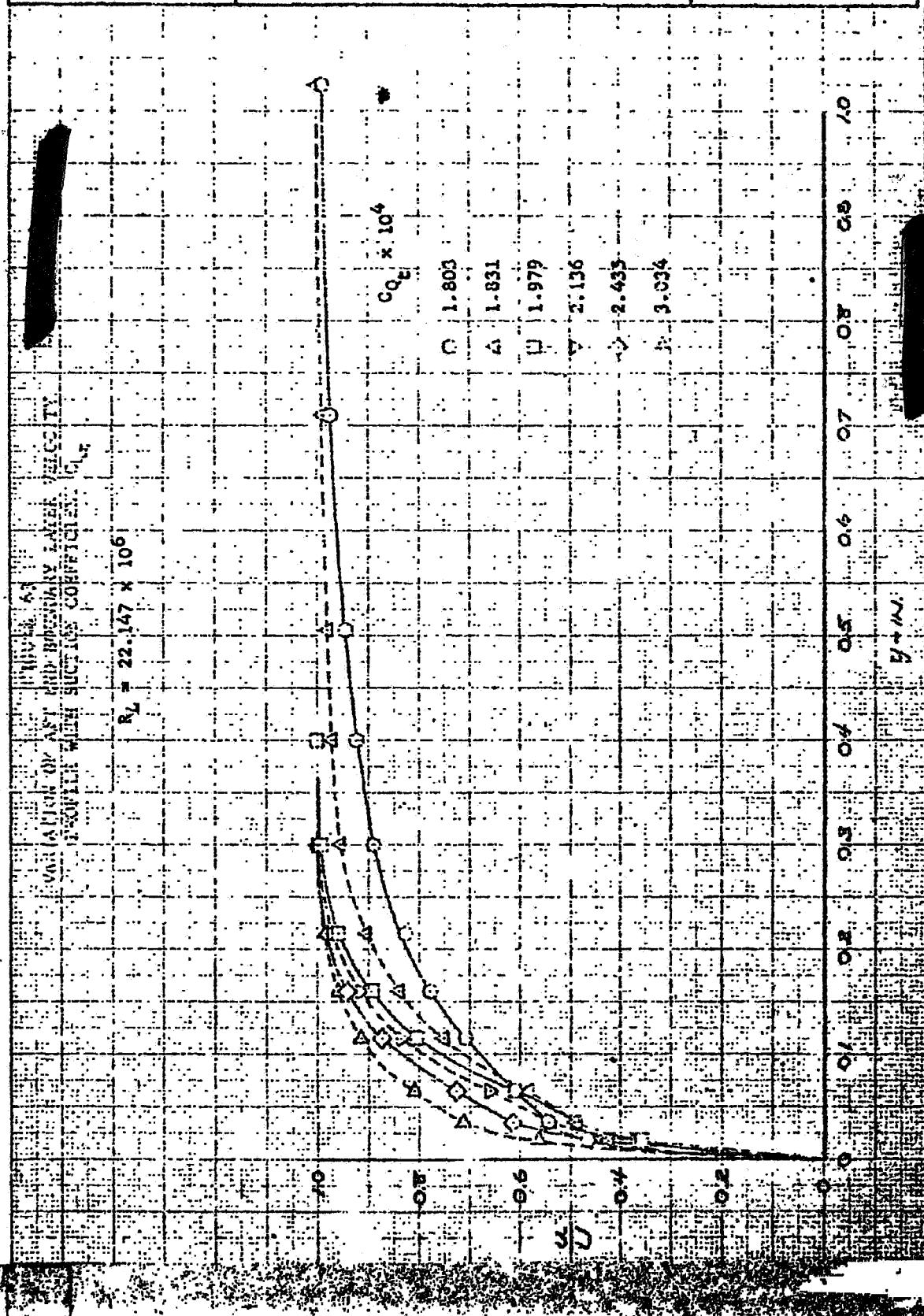
901 x 10⁶



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MODEL	



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RL = 30.306 x 10⁶

$C_{Q_E} \times 10^6$

0 1.616

A 1.658

D 1.696

V 1.906

▽ 2.248

△ 2.966

1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1

14 - 14

ANALYSIS OF THE STABILITY AND DYNAMIC
CHARACTERISTICS OF THE AIRCRAFT

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0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.0

2.532

2.346

2.120

1.980

1.907

1.880

1.915

1.914

1.913

1.912

1.911

1.910

1.909

1.908

BL = 30.424 x 106

WATERLINE OF DAY LINE
WATERLINE OF DAY LINE

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NORAIR DIVISION

REPORT NO.

MODEL

$$R_L = 37.989 \times 10^6$$

FEATURE 66
VARIATION OF APPENDAGE LENGTH
WITH POSITION OF CENTER OF GRAVITY $C_{QE} \times 10^4$

C 1.765

Δ 1.799

□ 1.860

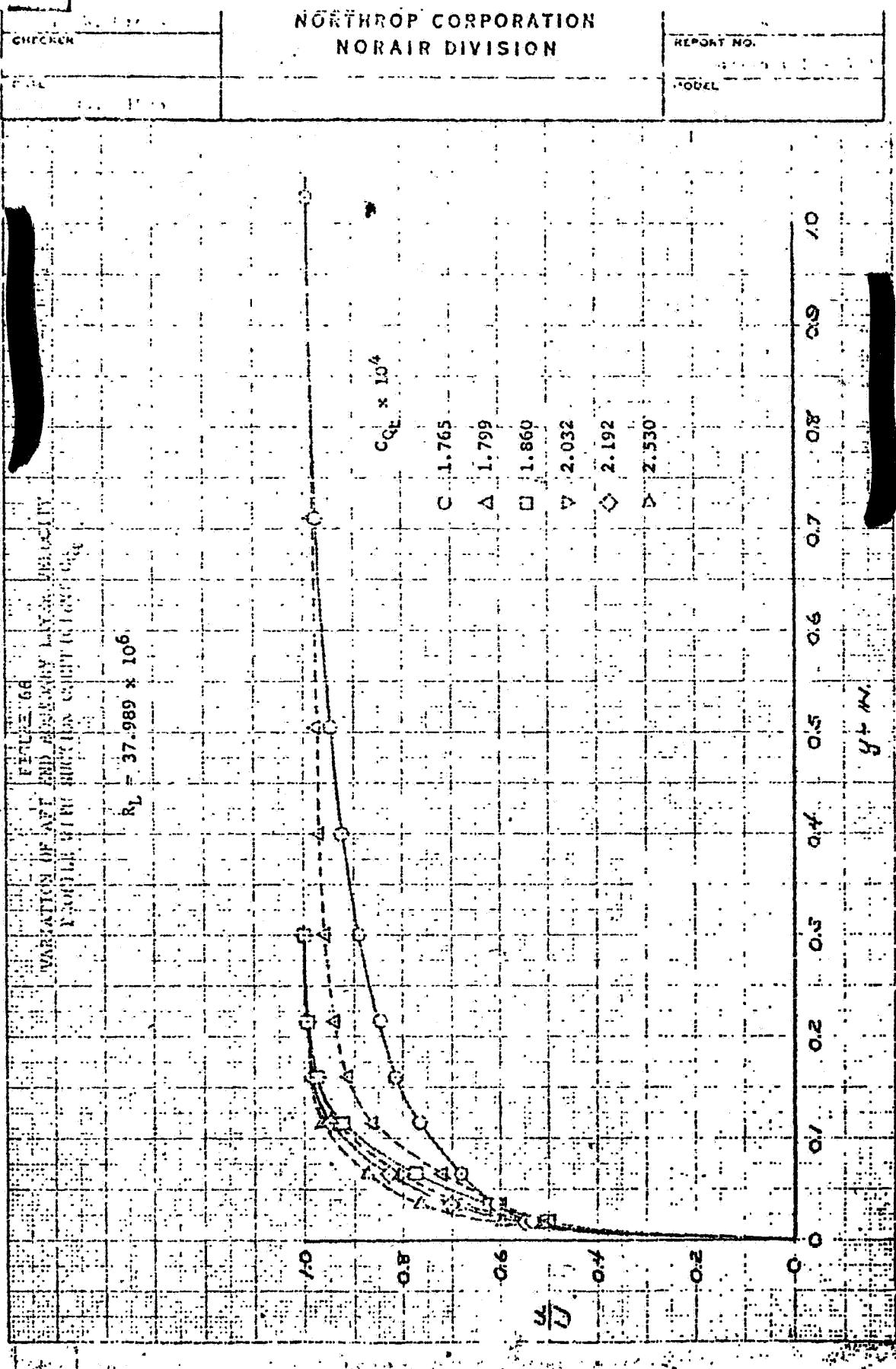
▽ 2.032

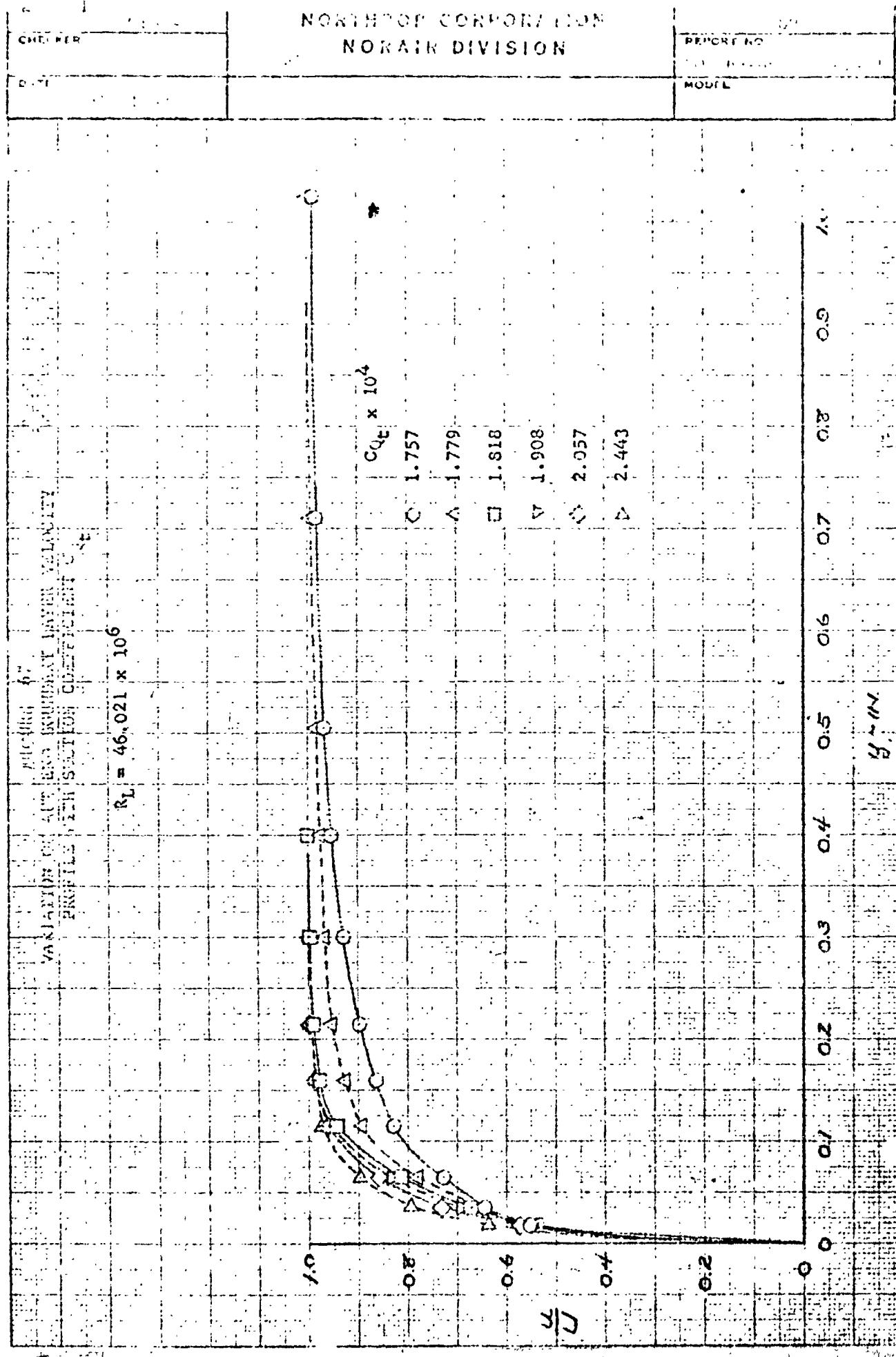
◇ 2.192

△ 2.530

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

Y + M





L. W. G.	NORTHROP CORPORATION NORAIR DIVISION	91
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DATE	NOR 63-46 (BLU-1)	MODEL

July 1963

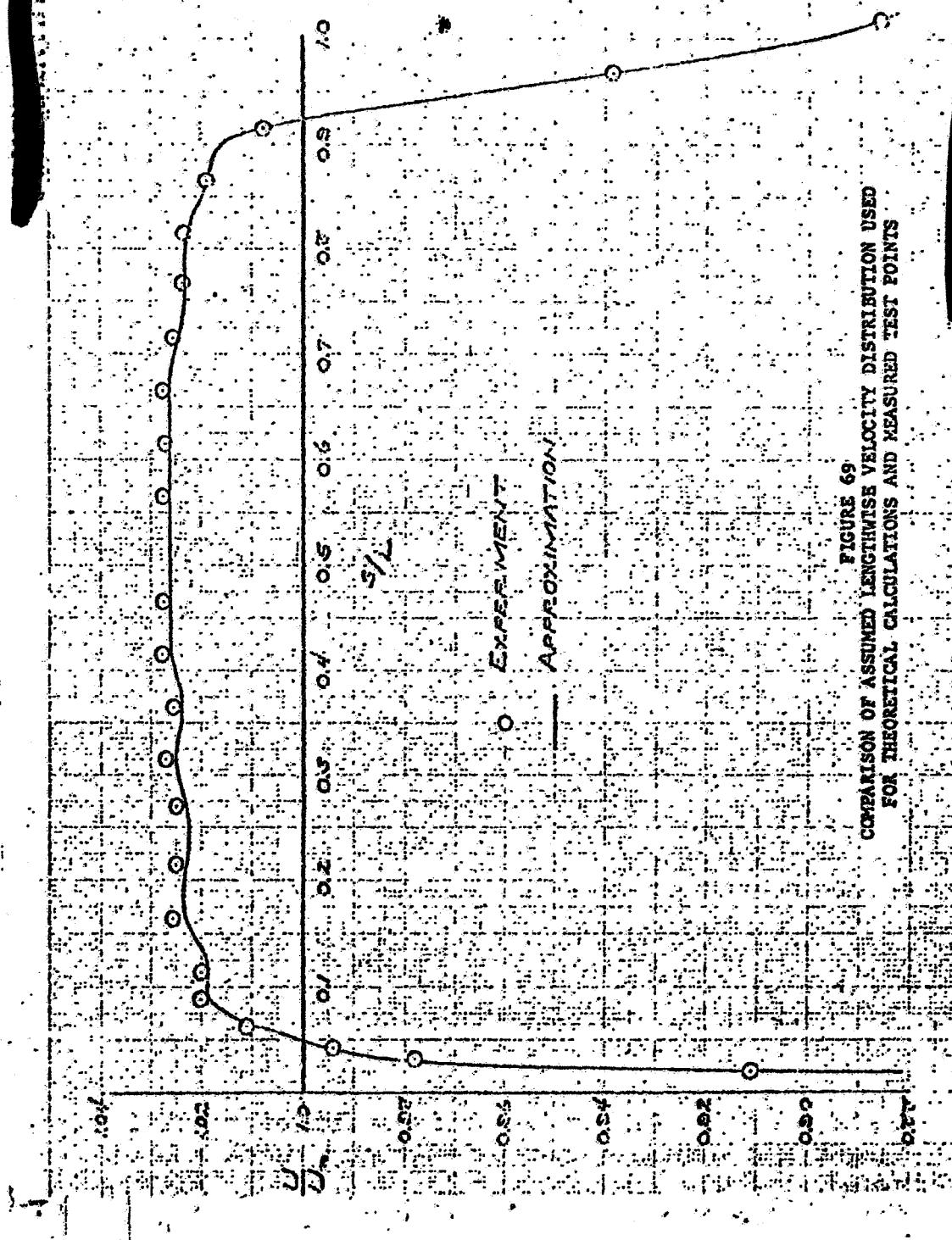
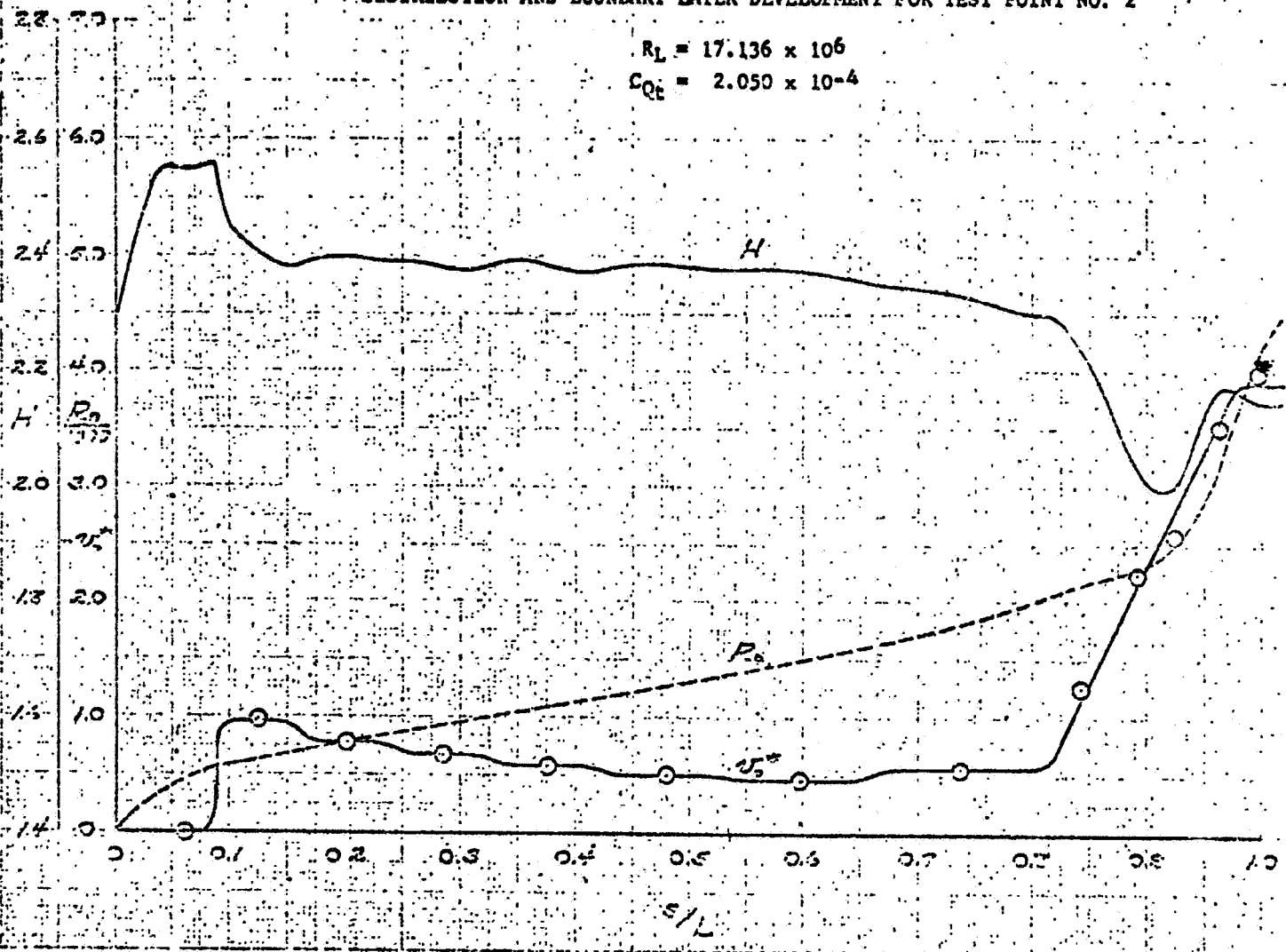


FIGURE 69
COMPARISON OF ASSUMED LENGTHWISE VELOCITY DISTRIBUTION USED
FOR THEORETICAL CALCULATIONS AND MEASURED TEST POINTS

FIGURE 70
NONDIMENSIONAL EQUIVALENT DISTRIBUTED SUCTION VELOCITY
DISTRIBUTION AND BOUNDARY LAYER DEVELOPMENT FOR TEST POINT NO. 2



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93

REPORT NO.
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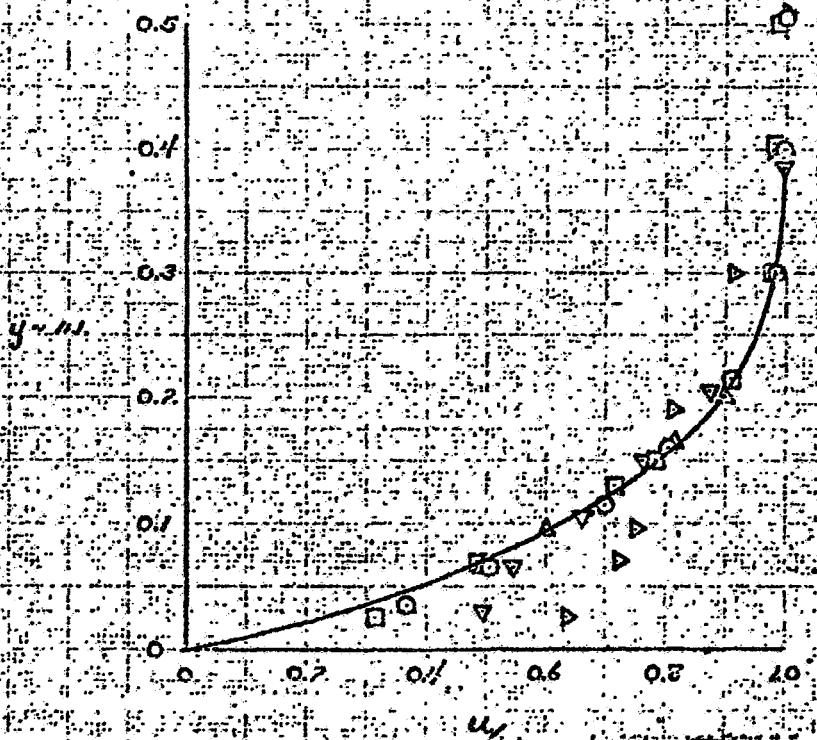
July 1963

FIGURE 71
COMPARISON OF CALCULATED AND MEASURED BOUNDARY
LAYER VELOCITY PROFILES AT REAR END OF
BODY FOR THE CONDITIONS OF TEST POINT NO. 2

$$R_1 = 17.136 \times 10^6$$

$$C_{Q_t} = 2.050 \times 10^{-4}$$

		CALC.				MEASURED			
		1	2	3	4	5	6	7	8
SYM.		○	△	□	▽	◇	▷	○	△
○		0.423	0.41	0.42	0.46	0.46	0.52	(m.)	
△		0.025	0.02	0.02	0.02	0.02	0.05	(m.)	
□		2.10	1.76	1.56	1.55	1.61	1.37		
▽		4.70	4.630	4.630	4.700	4.700	5.00		
◇		1.76			1.93				
○	$\delta_u \times 10^4$								

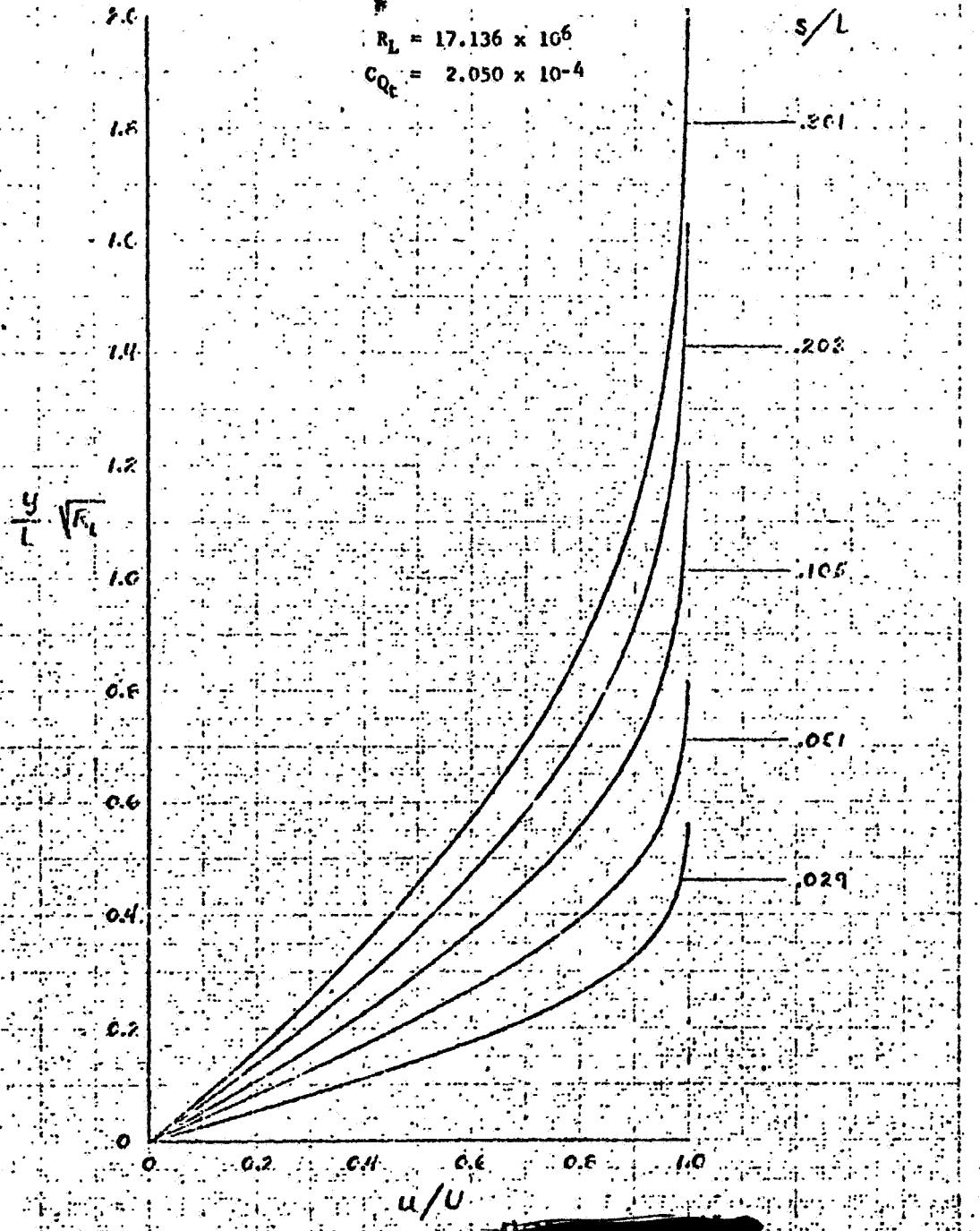


L. W. Gross	
CHECKER	
DATE	July 1963

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NORAIR DIVISION

94	
REPORT NO.	
NOR 63-46 (BLC-148)	
MODEL	

FIGURE 72a
CALCULATED BOUNDARY LAYER PROFILES AT VARIOUS LENGTHWISE
POSITIONS s/L FOR THE CONDITIONS OF TEST POINT NO. 2



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NORAIR DIVISION

95

REPORT NO.
NOR 63-46 (BLW-148)

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DATE
July 1963

FIGURE 72b
CALCULATED BOUNDARY LAYER PROFILES AT
VARIOUS LENGTHWISE POSITIONS ξ/L FOR THE
CONDITIONS OF TEST PCANT NO. 2

$$R_L = 17.136 \times 10^6$$

$$C_{Q_L} = 2.050 \times 10^{-4}$$

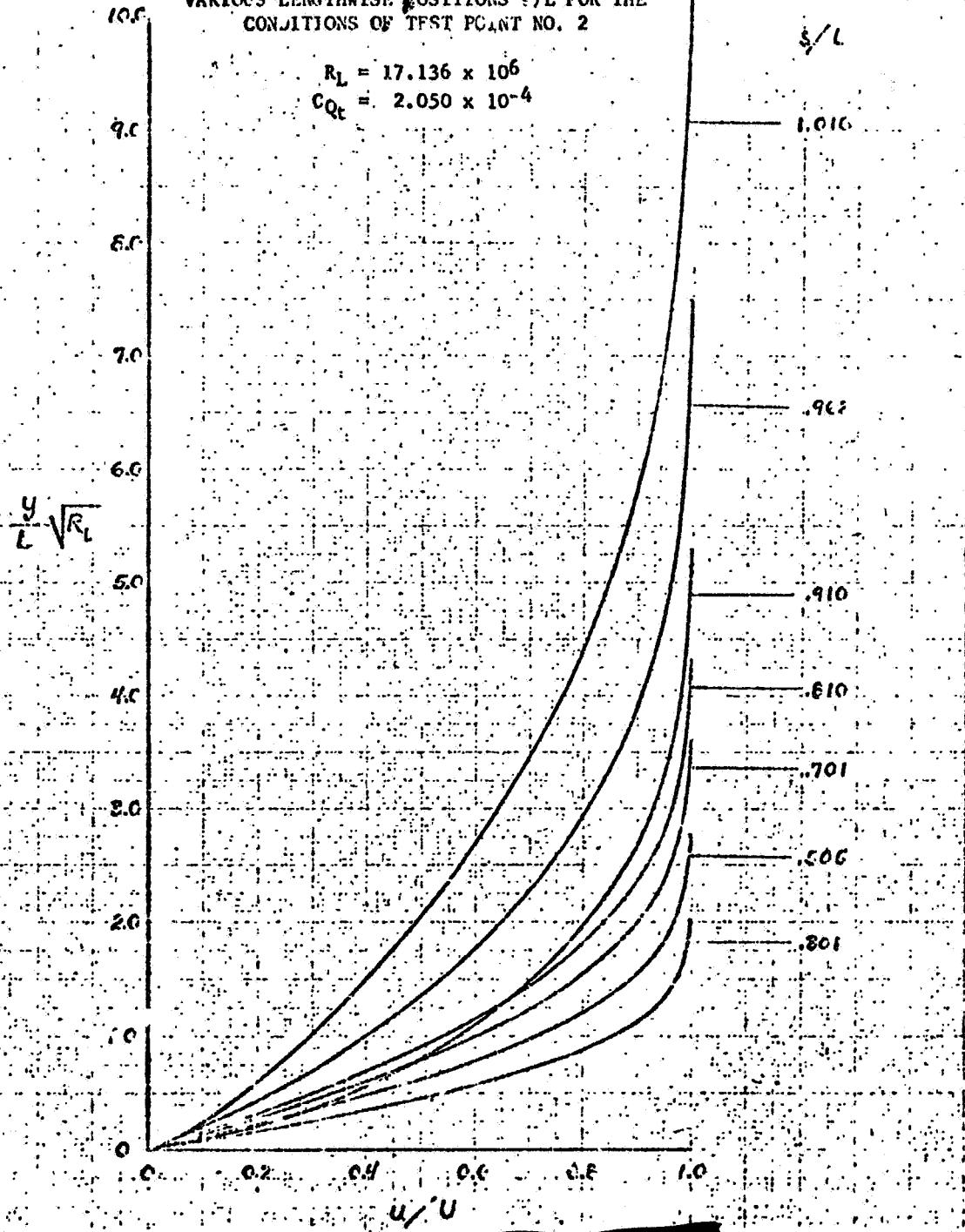
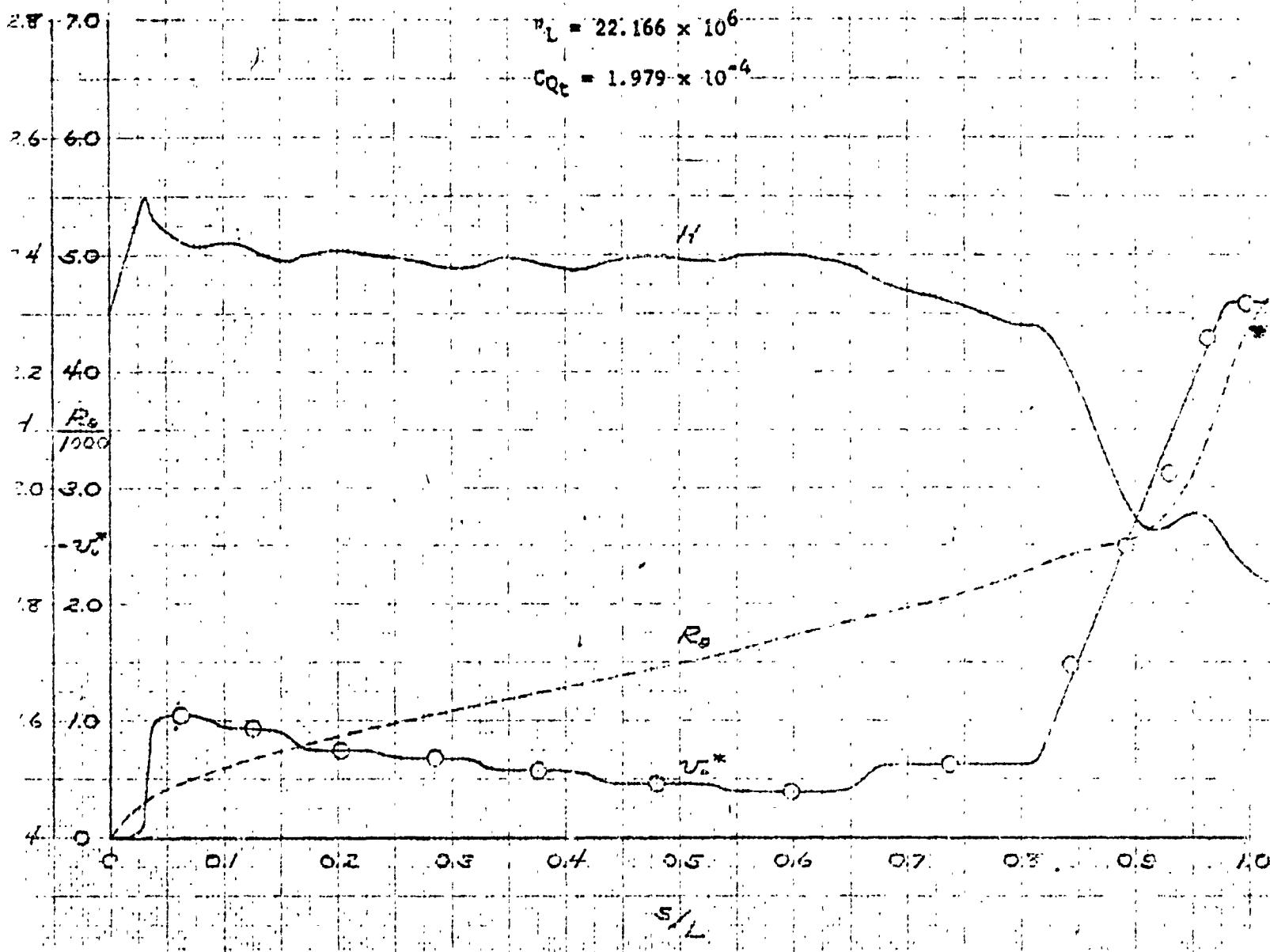


FIGURE 7A
NONDIMENSIONAL EQUIVALENT DISCHARGED SECTION
VELOCITY DISTRIBUTION AND ABORTOMETER LEVELS
A. DAY QUADRANT FOR TEST POINT NO. 102



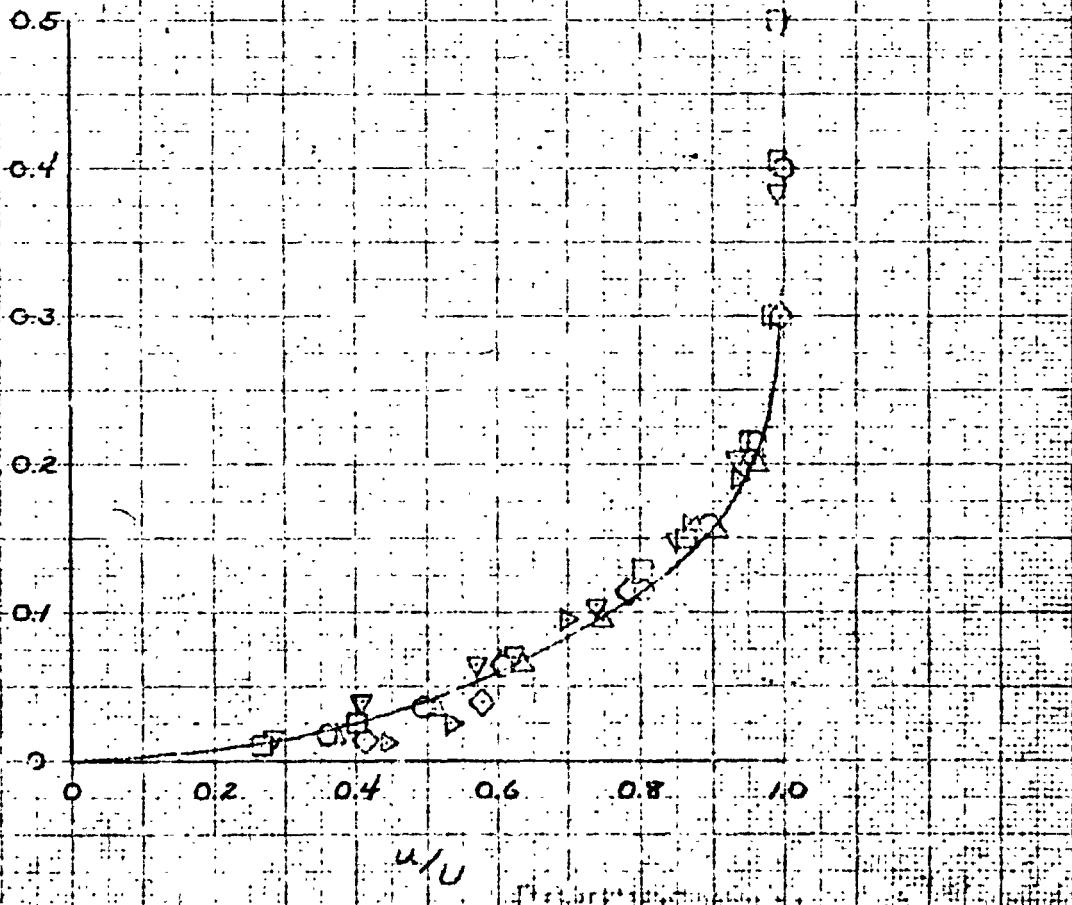
CHECKER	NORTHROP CORPORATION NORAIR DIVISION	REPORT NO. NO. 13-6117-1
DATE		MODEL

FIGURE 14
COMPARISON OF CALCULATED AND MEASURED COEFFICIENTS OF DRAG
FOR THE PROBLEM OF A RAKE IN A FLOW FIELD

$$R_L = 22.166 \times 10^6$$

$$C_{Q_t} = 1.979 \times 10^{-4}$$

RAKE NO.	CALC.		MEASURED			
	1	2	3	4	5	6
SYM.	○	△	□	▽	◇	▷
2	.0359	.0346	.0325	.0331	.0352	.0371
5*	.0622	.0560	.0522	.0522	.0550	.0512
11	1.838	1.647	1.624	1.725	1.721	1.564
R_g	4620	4640	4430	4920	5230	4800
C_{Q_t}, deg	1427			1459		



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NORAIR DIVISION**

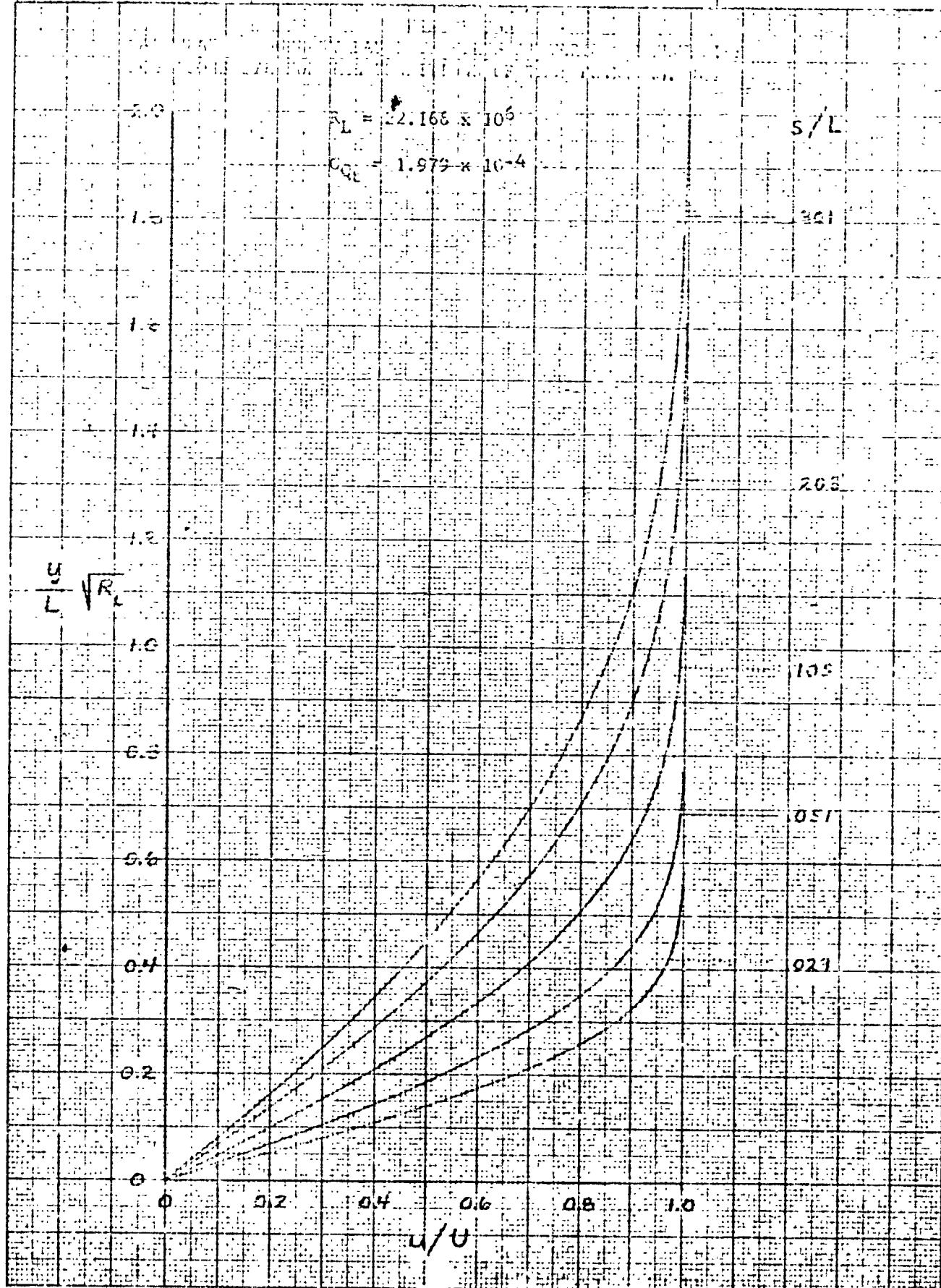
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NORAIN DIVISION

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DATE

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13.0

$$R_L = 2.166 \times 10^6$$

$$C_{Q_L} = 1.979 \times 10^{-4}$$

S/L

9.5

J.C. 12

E.G.

7.0

9.62

5.5

9.10

Y
L
VR

8.10

4.5

7.01

3.0

5.05

2.0

3.01

1.0

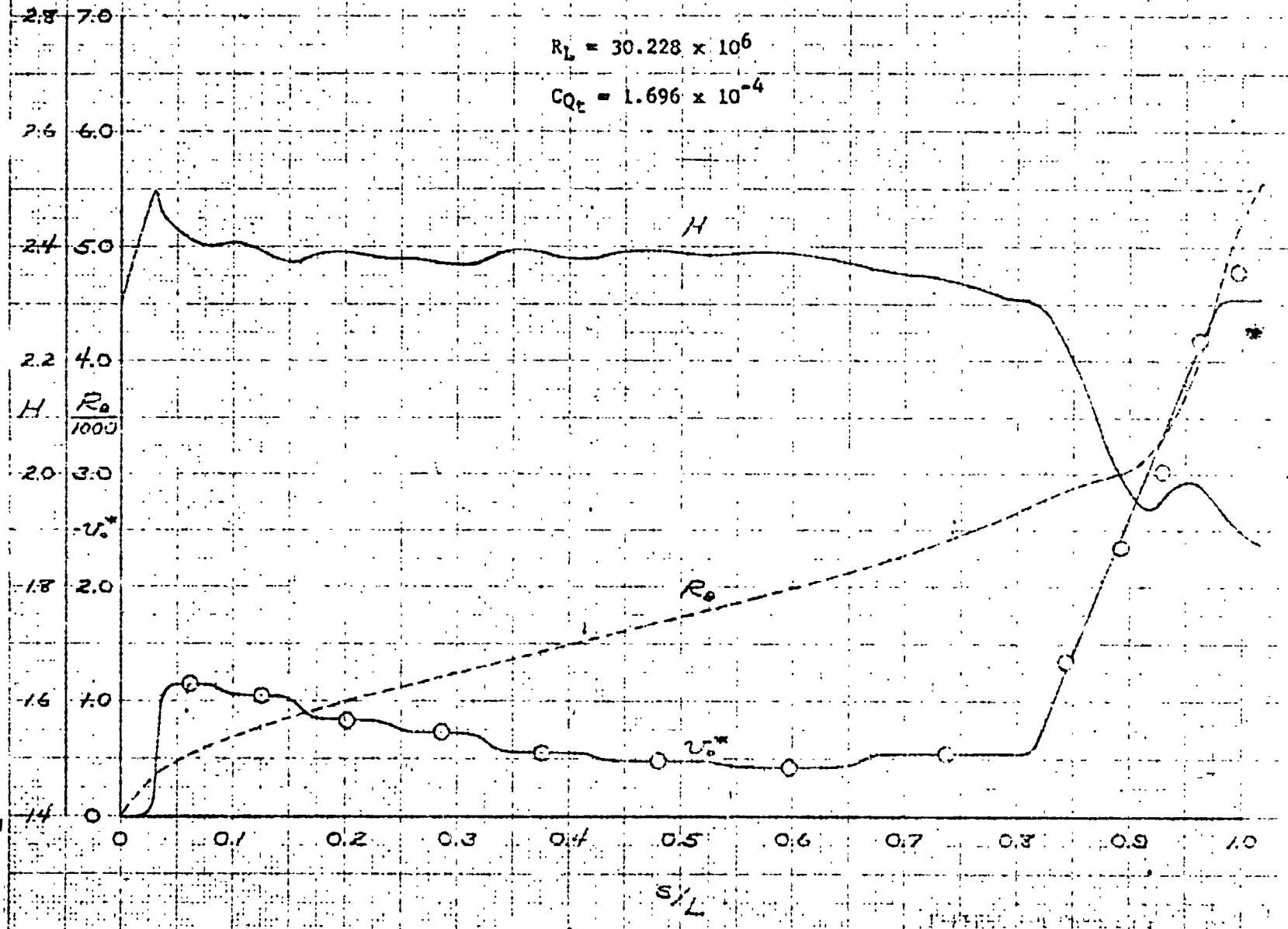
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0.1/U

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8.71

FIGURE 76
NONDIMENSIONAL EQUIVALENT DISTRIBUTED SUCTION
VELOCITY DISTRIBUTION AND BOUNDARY LAYER
DEVELOPMENT FOR TEST POINT NO. 47



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NORAIR DIVISIONREPORT NO.
10-6-14-300-101
MODEL

DATE

CONVERGENCE OF CFD & FLOW AND MEASURED WITH 3D LAMINAR
VISCOSITY COEFFICIENT FOR RAKE NO. 4

FOR THE CONDITION OF TEST POINT NO. 47

$$R_L = 30.228 \times 10^6$$

$$C_{Q_L} = 1.696 \times 10^{-4}$$

CALC.

MEASURED.

RAKE NO.

1 2 3 4 5 6

SYIA.

○ △ □ ▽ ◇ ▷

θ

0.296 0.305 0.278 0.313 0.308 0.311 0.317 (ML)

ε²

0.555 0.486 0.447 0.508 0.522 0.463 0.454 (ML)

H

1.876 1.425 1.605 1.624 1.682 1.455 1.431

R₀

5520 5680 5190 5240 5750 5290 5820

C_{D0} × 10⁴

1.255 1.257

0.5

0.4

0.3

0.2

0.1

0.0

y/in.

FIGURE 10-6-14-300-101

u/u

0.2

0.4

0.6

0.8

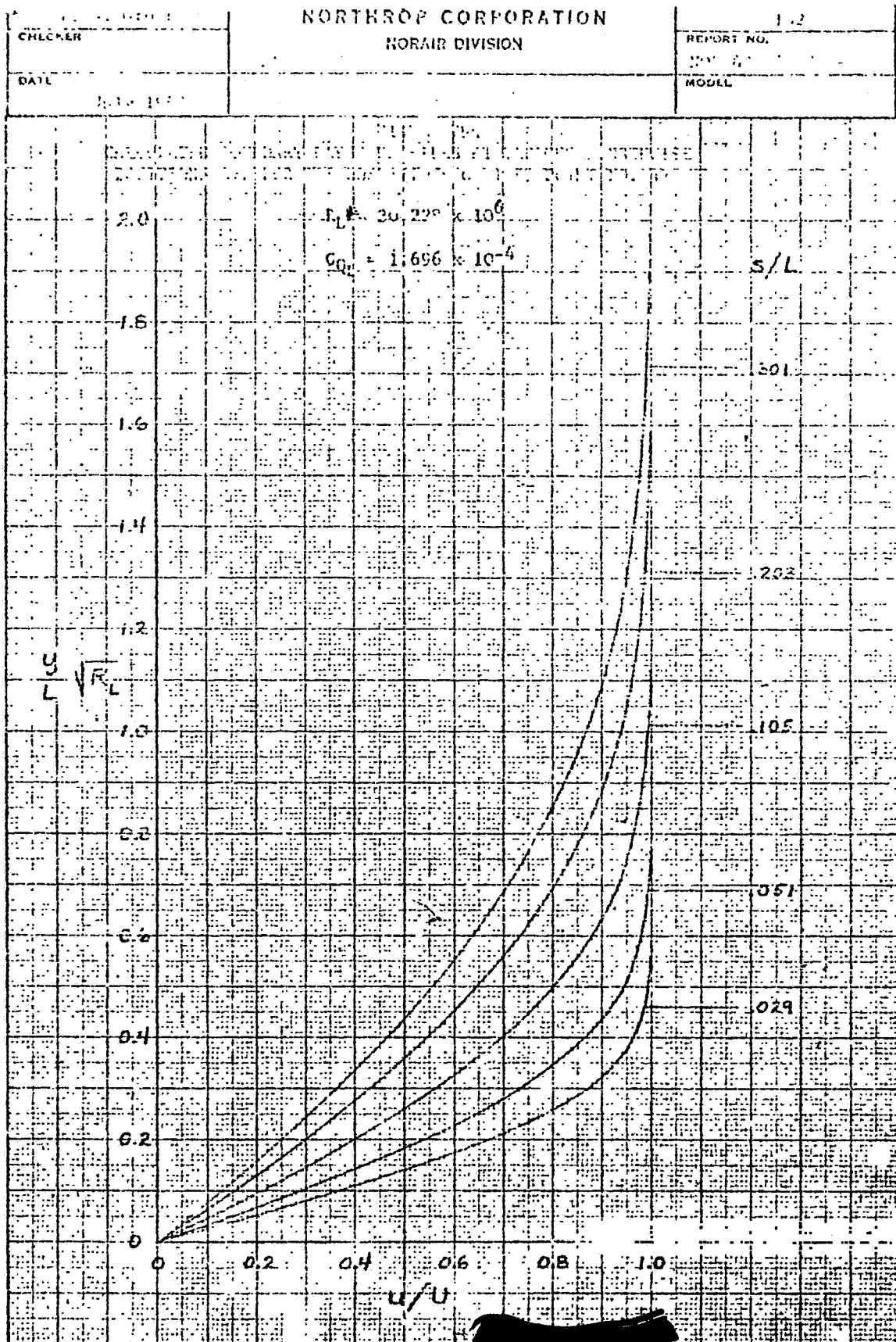
1.0

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NORAIR DIVISION**

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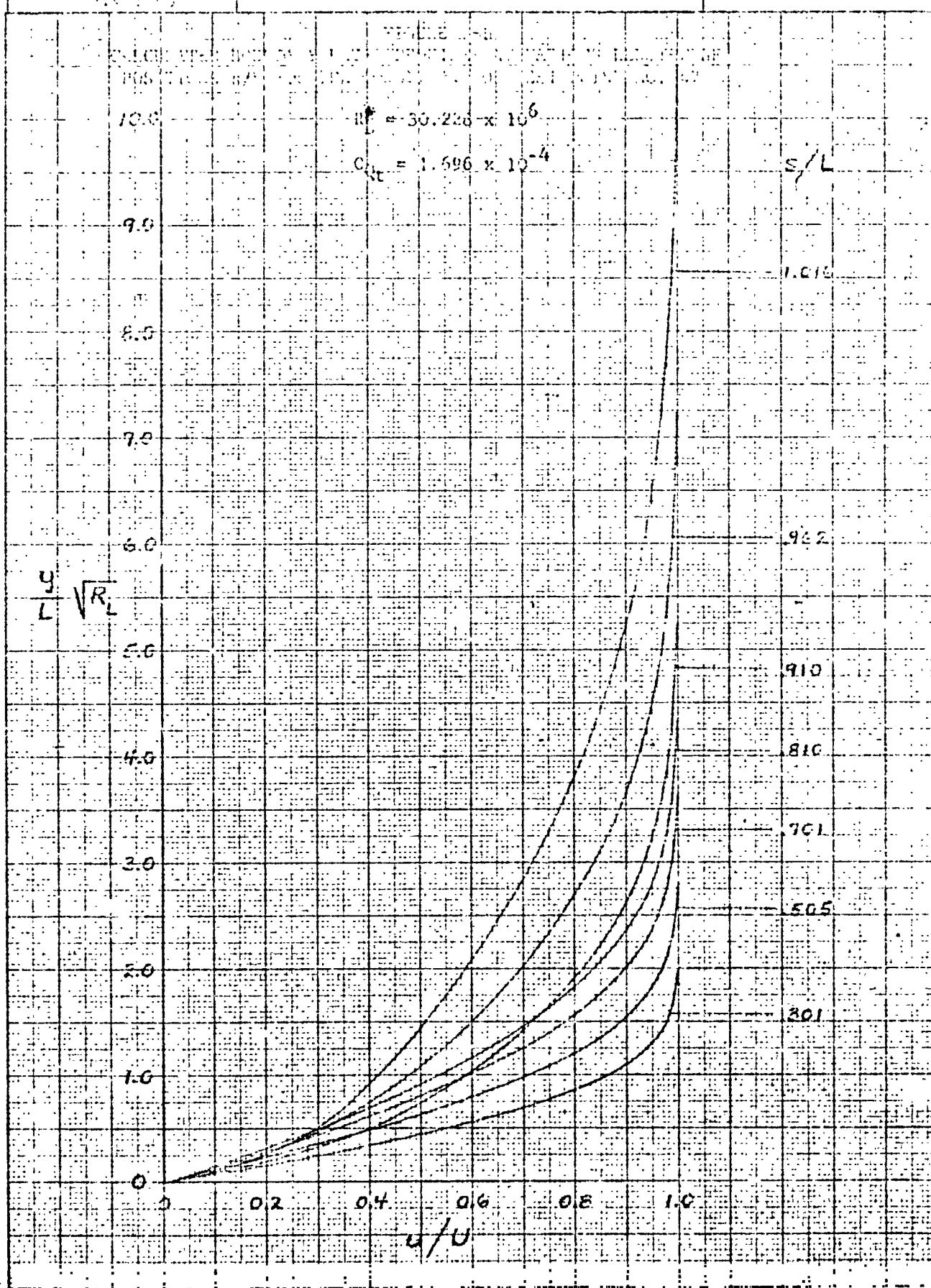
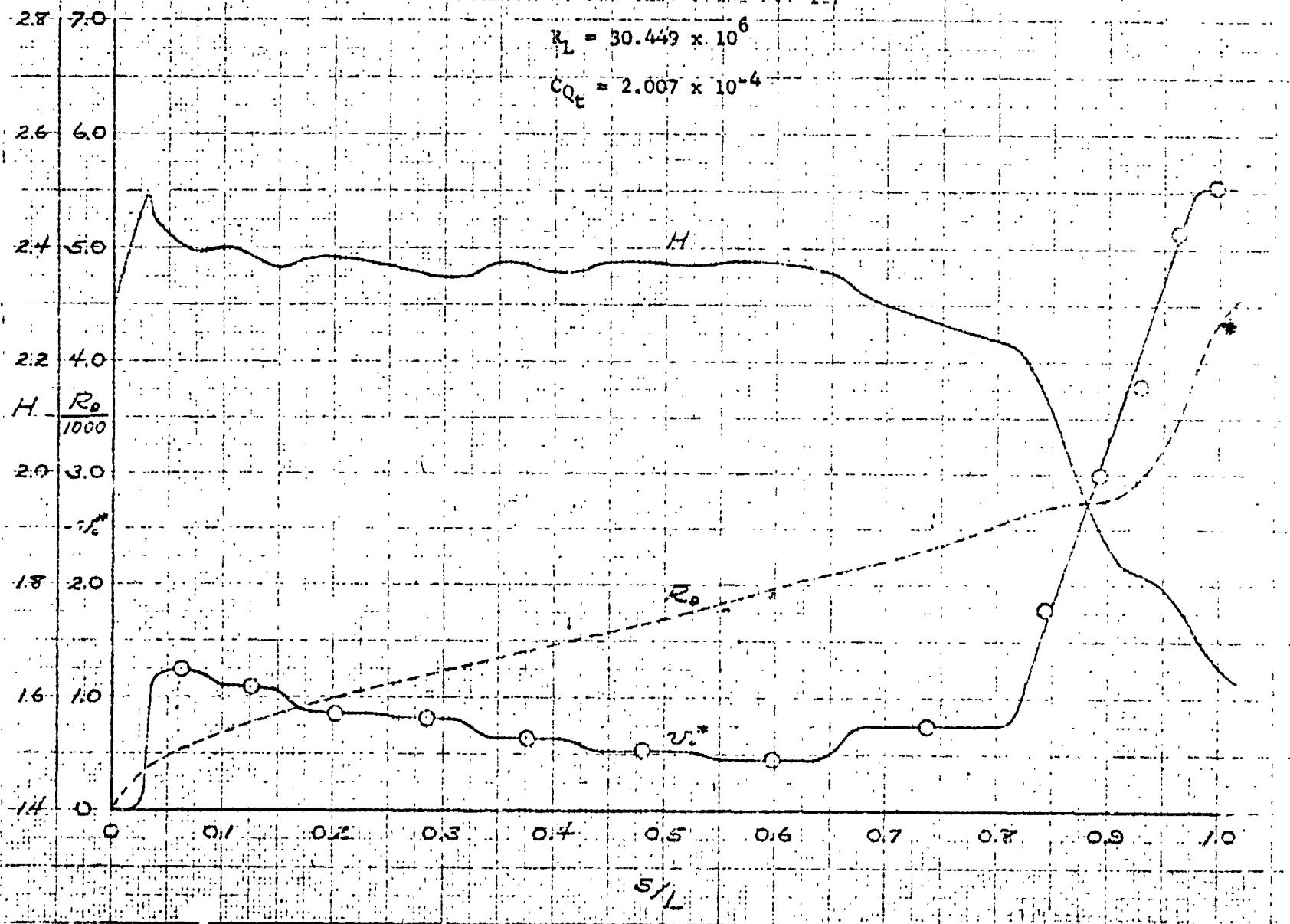


FIGURE 79
NONDIMENSIONAL EQUIVALENT DISTRIBUTED SUCTION
VELOCITY DISTRIBUTION AND DOWNSET LAYER
DEVELOPMENT FOR TEST POINT NO. 117



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NORTHROP CORPORATION
NORAIR DIVISION

REPORT NO.
NOR-63-56

DATE

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SUM-111

FINAL DATA
COMPARISON OF CALCULATED AND MEASURED COEFFICIENT OF FRiction
AND ADHESION COEFFICIENT FOR
FOR THE CONDITIONS OF TEST POINT NO. 117

$$R_e = 30,449 \times 10^6$$

$$C_{ct} = 2.007 \times 10^{-4}$$

CALC.

MEASURED

RAKE NO.

SYM

P

1 O △ □ V ◇ △ (N)

B*

0394 0249 0339 0376 0423 0350 0367 (N)

H

1.630 1.462 1.425 1.518 1.520 1.417 1.422

R₀

4530 4480 4390 4350 5230 4630 4630

$C_{ct} > 10^4$

1.013 1.056

0.5

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0.2 0.4 0.6 0.8 1.0

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28

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CONFIDENTIAL - BY THE ESTIMATES OF WALTER'S AND LINDENBERG
POSITIONS ARE THE ESTIMATES OF 2000, 5000, 1175

$$R_L = 30.449 \times 10^6$$

$$C_0 = 2.007 \times 10^{-4}$$

5/1

501

• • •

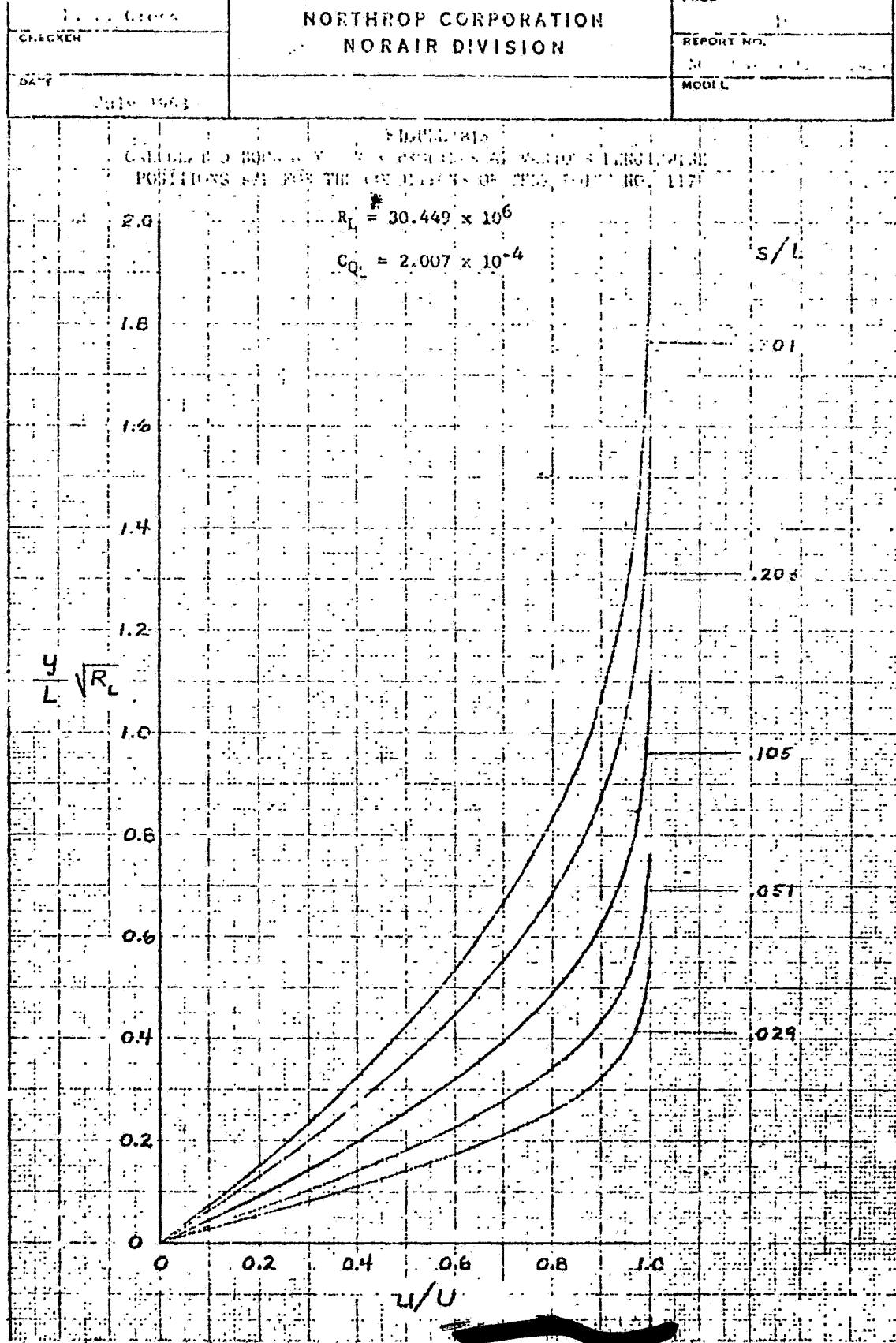
1303

105

051

238

028



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NORAIR DIVISION

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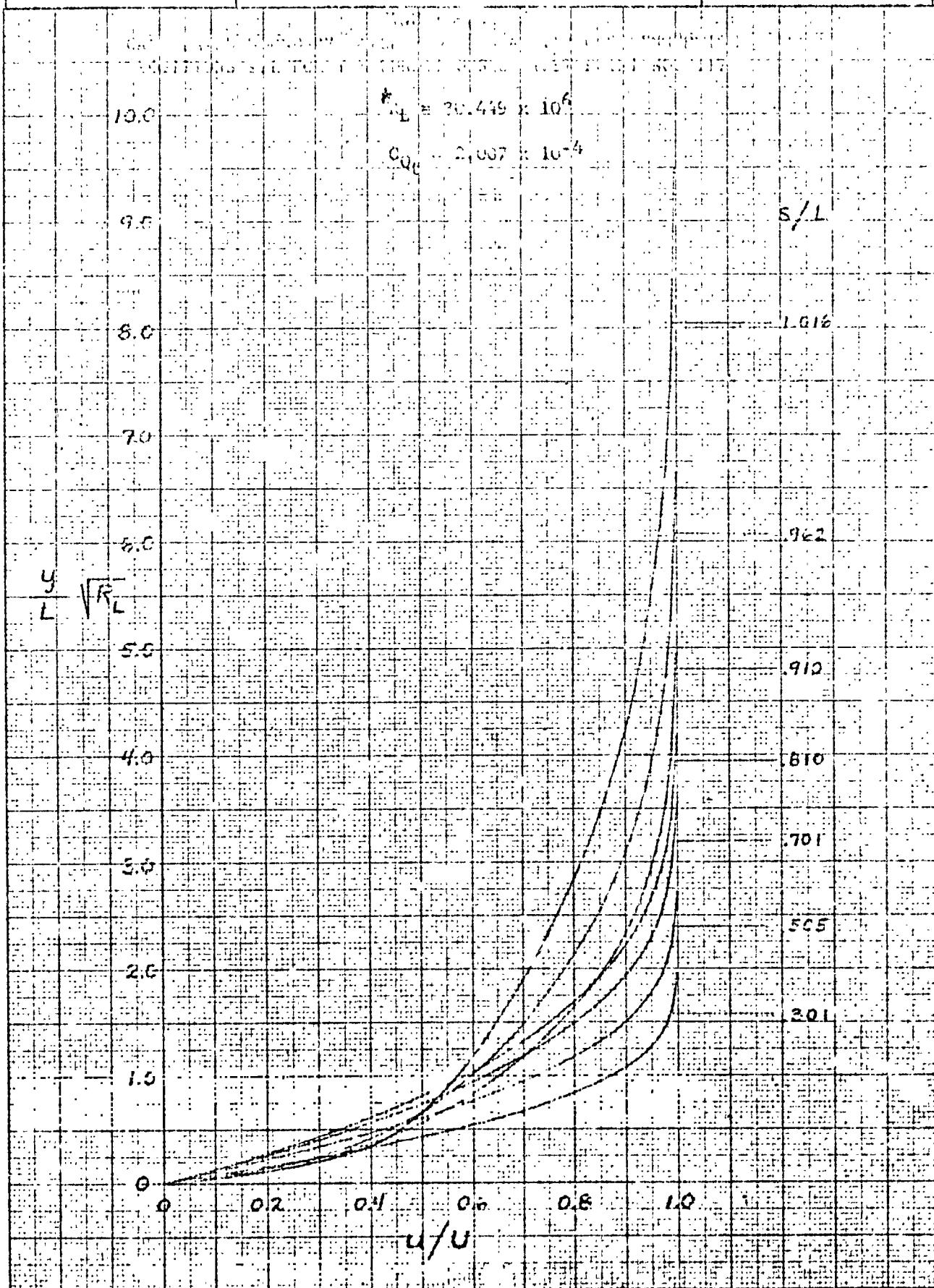
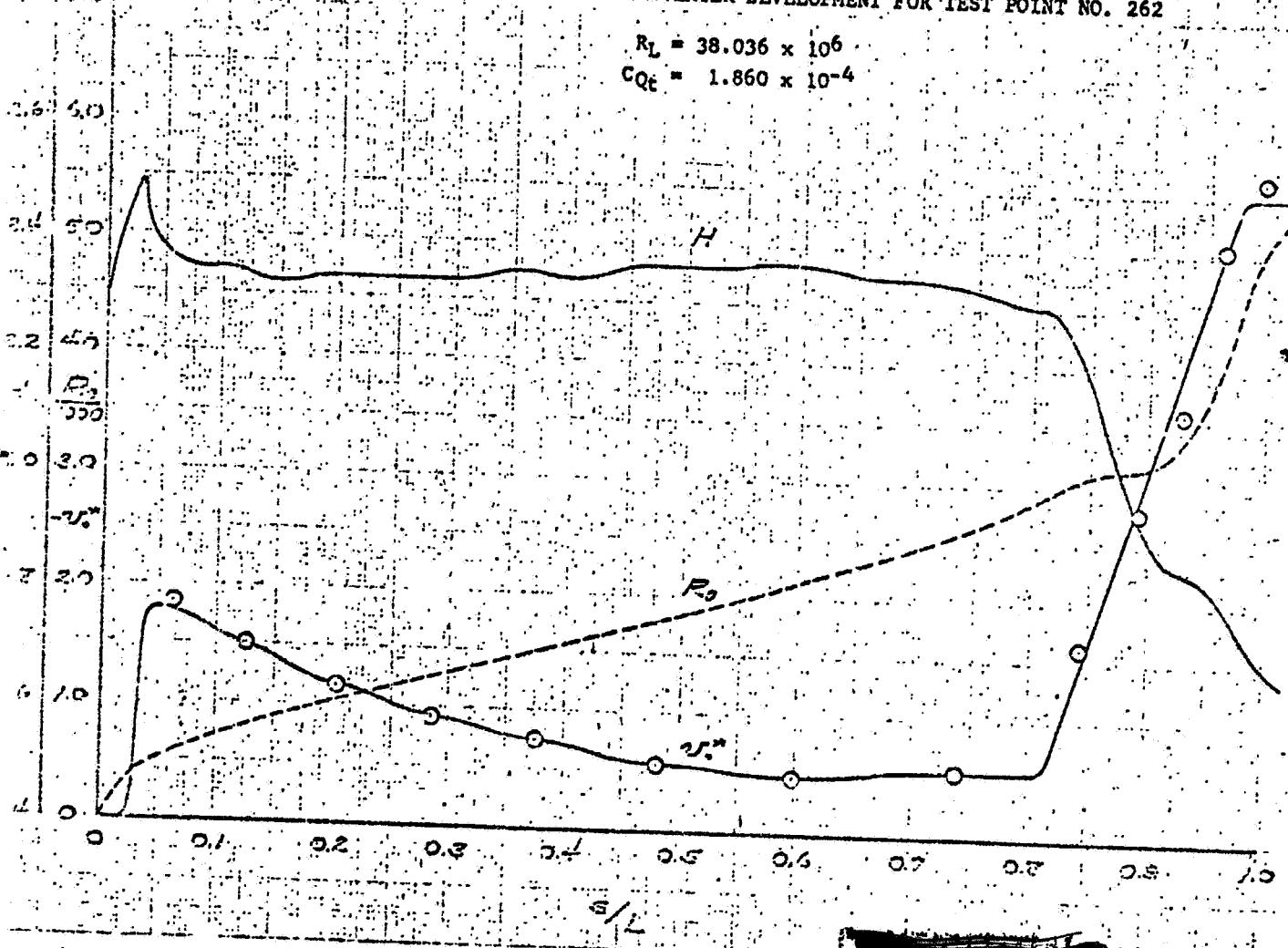


FIGURE 82
NONDIMENSIONAL EQUIVALENT DISTRIBUTED SUCTION VÉLOCITÉ
DISTRIBUTION AND BOUNDARY LAYER DEVELOPMENT FOR TEST POINT NO. 262

$$R_L = 38.036 \times 10^6$$

$$C_{Qe} = 1.860 \times 10^{-4}$$



L. W. Gross	NORTHROP CORPORATION NORAIR DIVISION	109
CHECKER		REPORT NO.
DATE	July 1963	NOR 63-46 (SLC-148)

FIGURE 83
COMPARISON OF CALCULATED AND MEASURED BOUNDARY
LAYER VELOCITY PROFILES AT REAR END OF
BODY FOR THE CONDITIONS OF TEST POINT NO. 262

$$R_L = 38,036 \times 10^6$$

$$C_{Q_L} = 1.860 \times 10^{-4}$$

CALC. MEASURED

RAKE NO.	1	2	3	4	5	6
SYM	—	○	△	□	▽	◇
0°	0.026	0.021	0.020	0.021	0.023	0.025
5°	0.024	0.031	0.029	0.036	0.042	0.049
H	1.67	1.15	1.16	1.19	1.16	1.36
R ₀	6780	6600	7220	5620	6650	7150
C _{Q_L10}	1.02	—	—	1.10	—	—

0.5

0.4

0.3

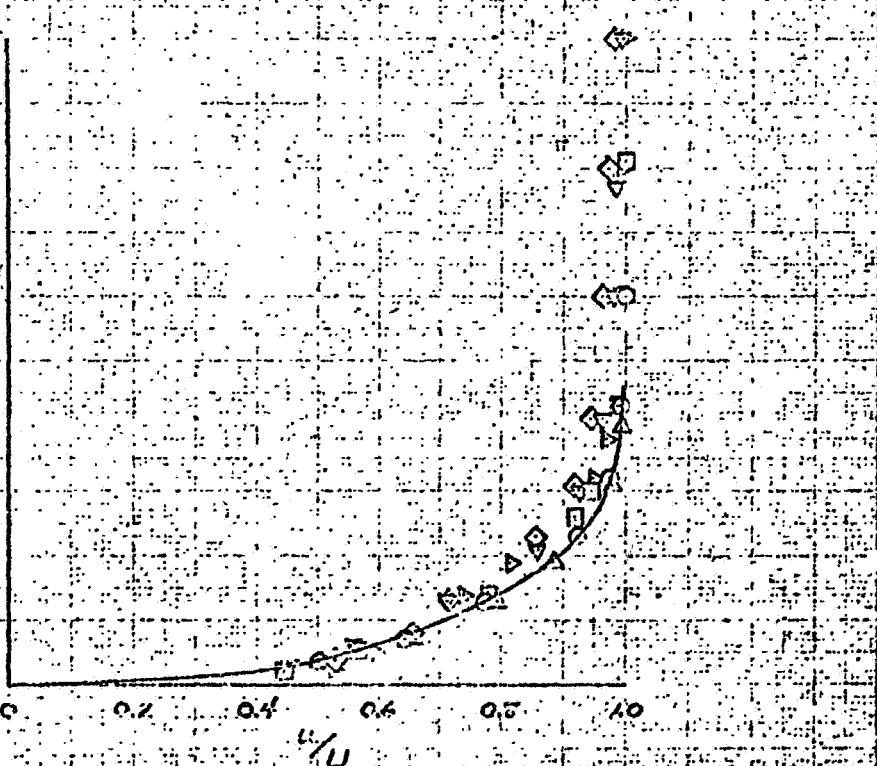
y/m.

0.2

0.1

0.2 0.4 0.6 0.8 1.0

U/U



L. W. Giese
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NORTHWEST CORPORATION
NORAIR DIVISION

DATE
July 1963

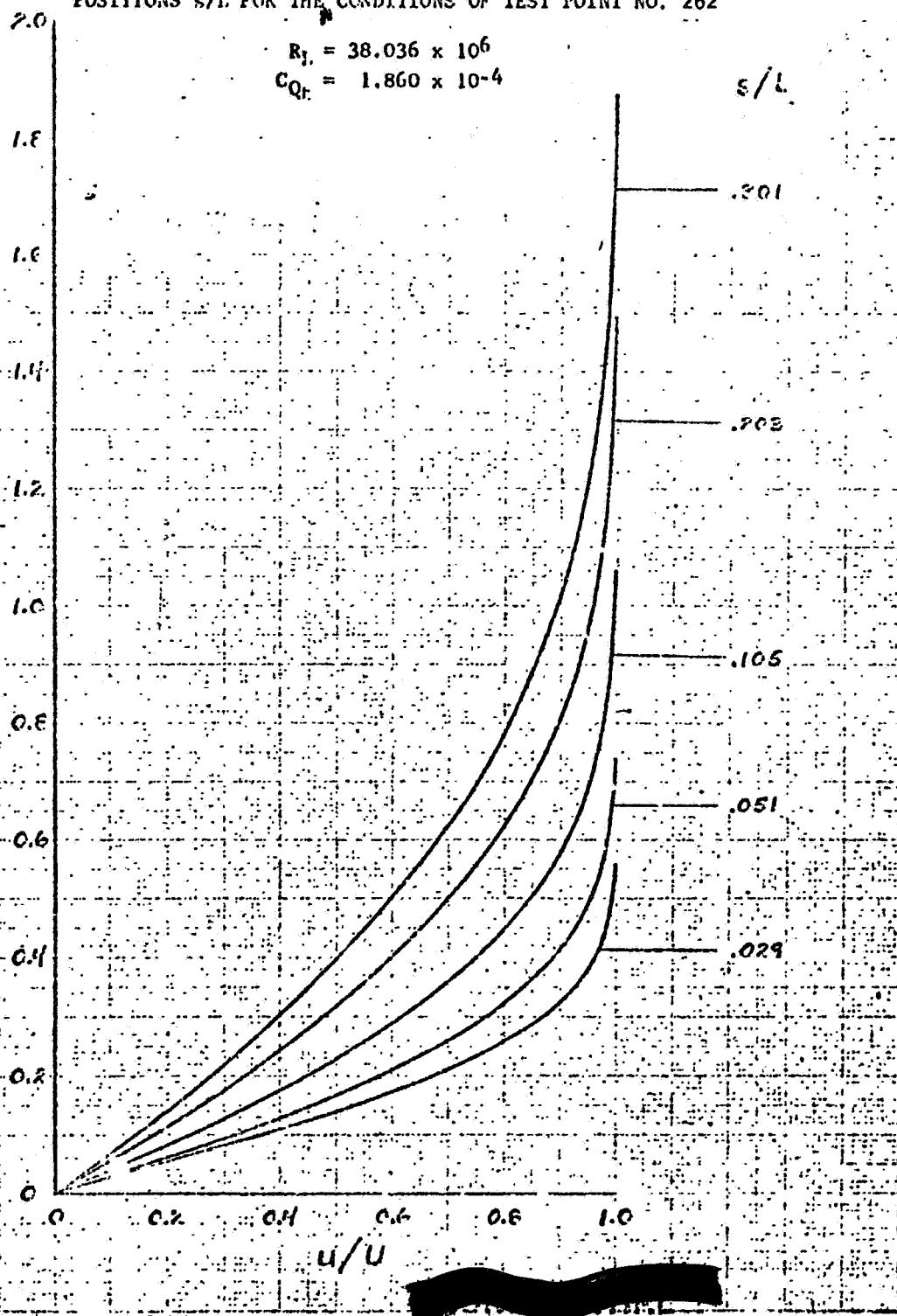
110
REPORT NO.
NOR 63-46 (BIC-14E)
MODEL

FIGURE 84a

CALCULATED BOUNDARY LAYER PROFILES AT VARIOUS LENGTHWISE
POSITIONS s/L FOR THE CONDITIONS OF TEST POINT NO. 262

$$R_i = 38.036 \times 10^6$$

$$C_{Q_r} = 1.860 \times 10^{-4}$$



L. V. Gross	
CHECKER	
DATE	
July 1963	

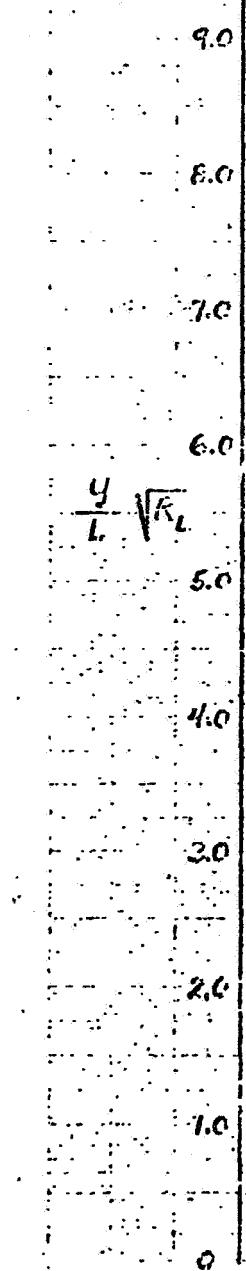
NORTHROP CORPORATION
NORAIR DIVISION

III

REPORT NO.
NOR 63-46 (BLG-14S)

MODEL

IC.C



$$R_L = 38.036 \times 10^6$$

$$C_{Q_t} = 1.860 \times 10^{-4}$$

s/L

IC.C

962

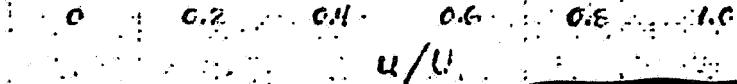
910

810

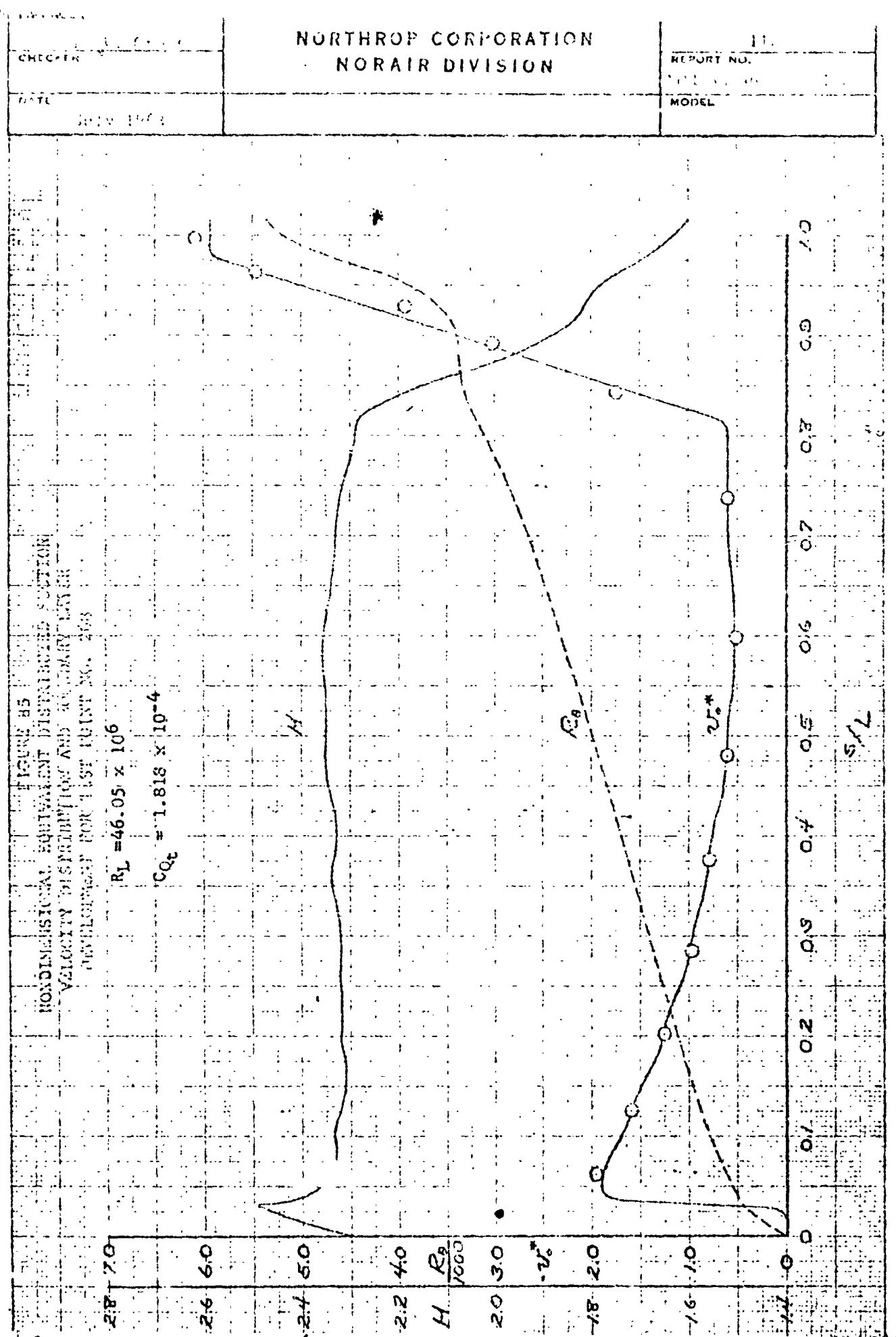
708

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301



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 NORAIR DIVISION

REPORT NO.

A-61-471-1000

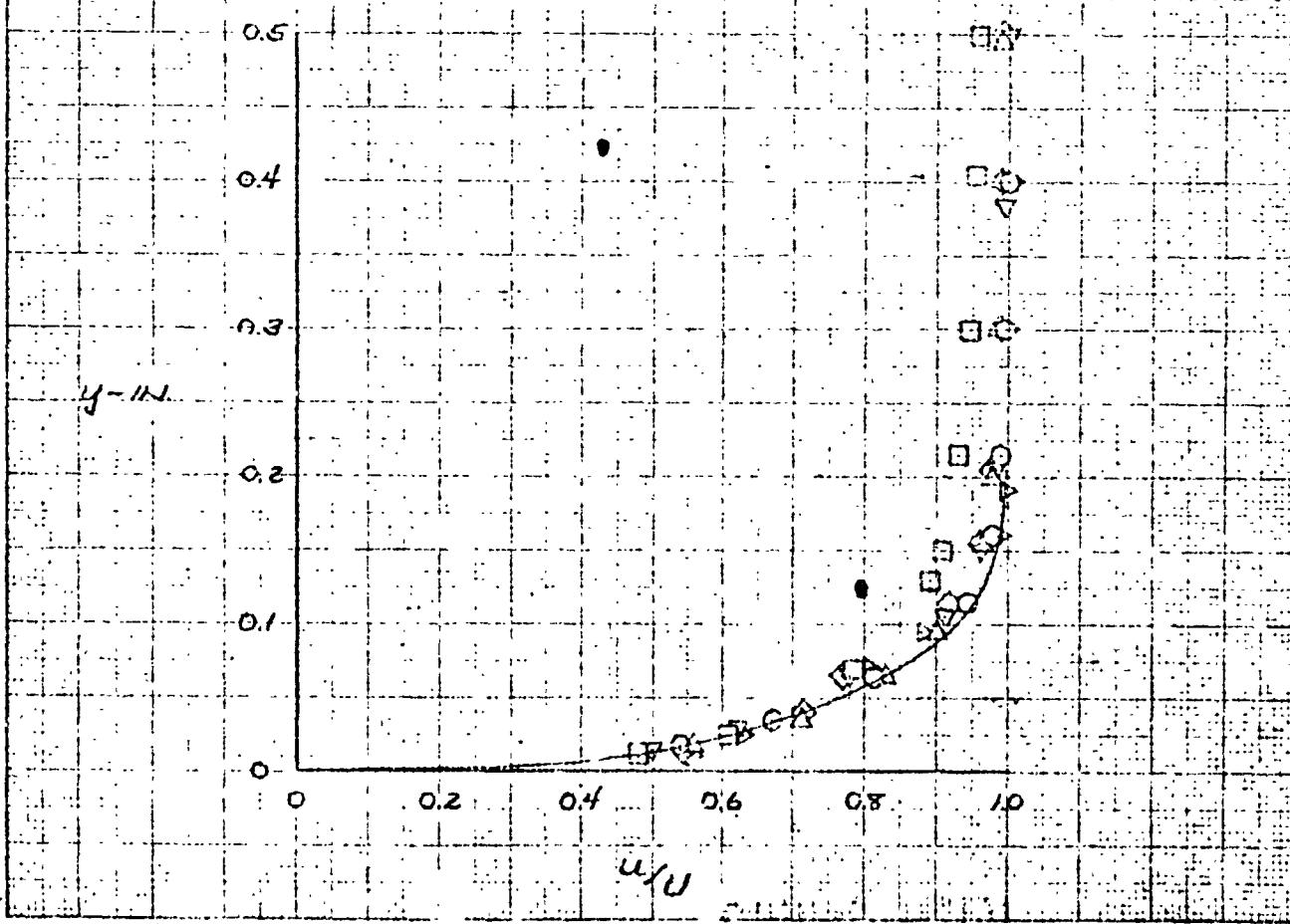
MOLLE

CC-1300 LF. PLATE, LR. INLET, 1.0 MM. LAYER
 1.0 MM. PLATE, 1.0 MM. LAYER
 0.1 MM. PLATE, 0.1 MM. LAYER

$$R_L = 45.05 \times 10^6$$

$$C_{Q_t} = 1.816 \times 10^{-4}$$

RAKE NO.	CALC.						MEASURED					
	1	2	3	4	5	6	1	2	3	4	5	6
SYM	-	○	△	□	▽	◊	▷	○	△	□	▽	◊
θ	0.159	0.158	0.217	0.221	0.203	0.208	(N)					
δ^*	0.303	0.260	0.285	0.317	0.282	0.290	(A)					
H	1.620	1.418	1.311	1.430	1.388	1.395						
R_s	5350	5330	6150	6260	5750	5500						
$C_{Q_t} \times 10^4$	0.891			0.896								



NORTHROP CORPORATION
NON-AIR DIVISION

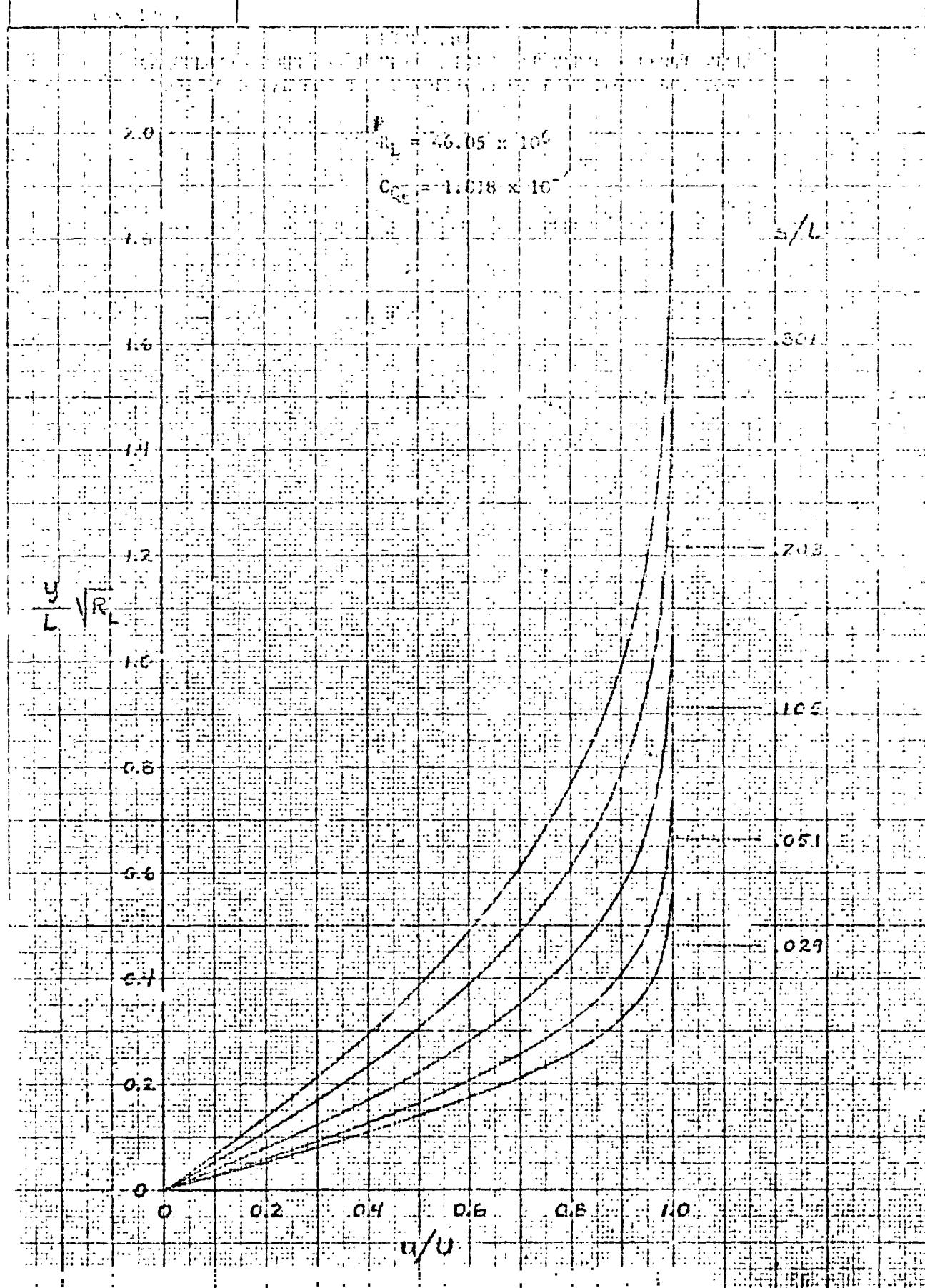
REPORT NO.

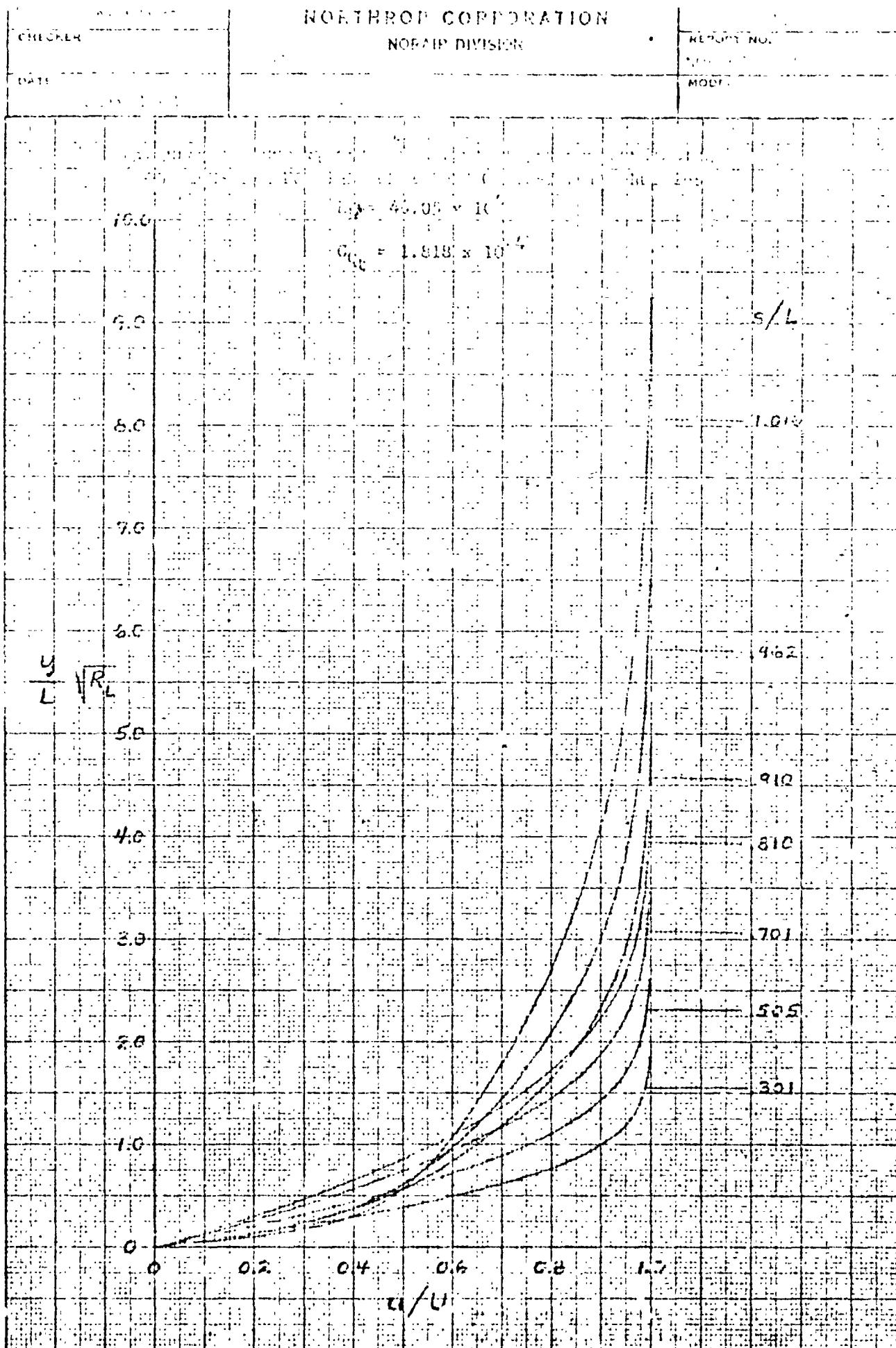
NON-AIR-100

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NORAIR DIVISION

REPORT NO.
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FIG. C. 9A

WAVELENGTHS OF 1-YEAR-SPANNING INFRARED SPECTRUM
FOR THE 1000-10000 CM⁻¹ REGION

2.0

$$R_L = 56.74 \times 10^6$$

-1.8

$$C_{Q_L} = 1.789 \times 10^{-4}$$

-1.6

S/I.

-1.4

301

-1.2

203

$$\frac{y}{L} \sqrt{r_2}$$

-1.0

105

-0.8

051

-0.6

025

-0.4

0.2

0

0

0.2

0.4

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444

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NO. 1 MODEL CALIBRATION
NOMARL DIVISION

FLIGHT

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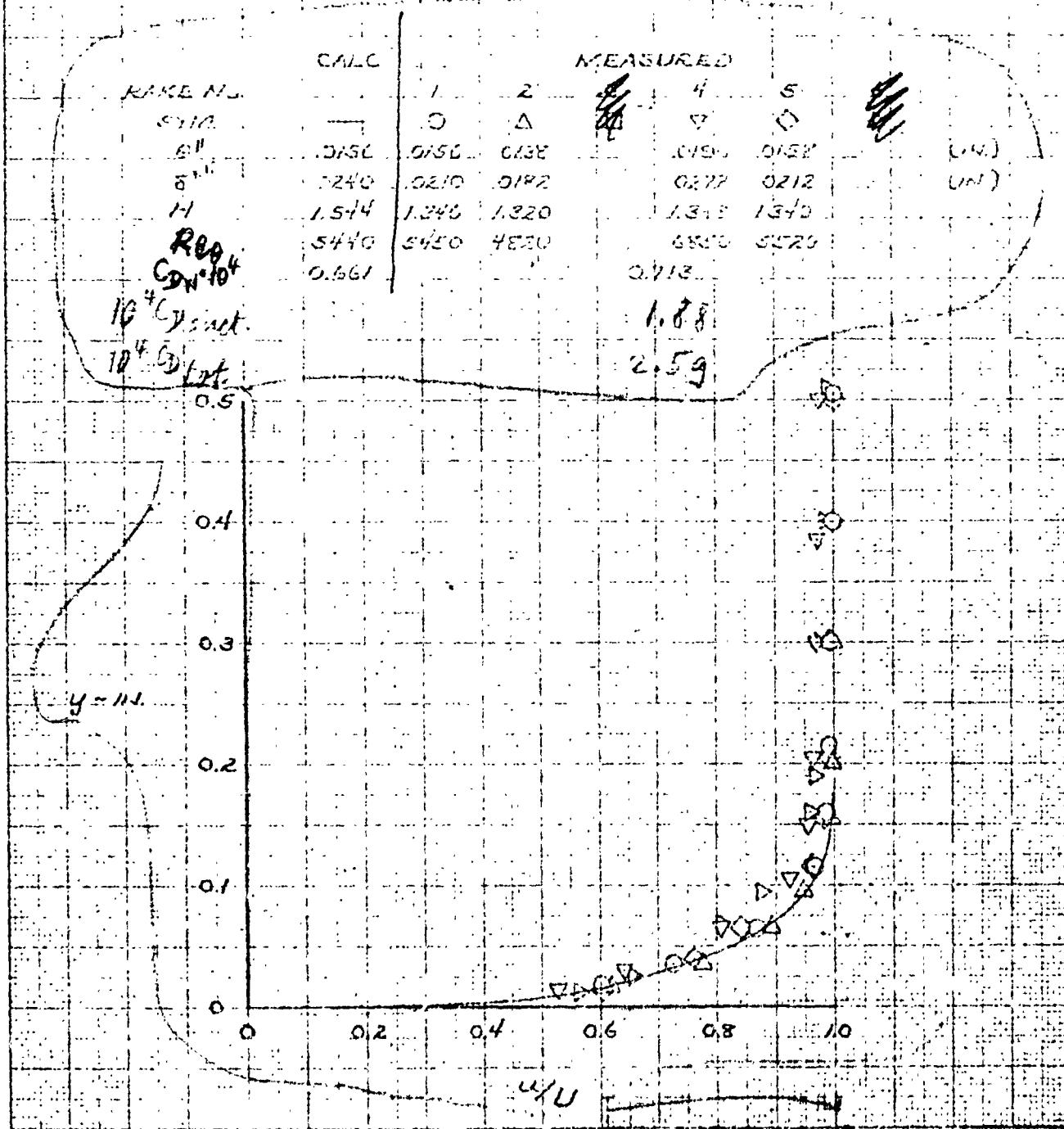
Richardt LFC body (L/D=8)

Cf = 0.00125 + 0.00000125 D^2 - 0.00000001 D^4

Cf = 0.00125 + 0.00000125 D^2 - 0.00000001 D^4

$$Re = 56.74 \times 10^6$$

$$C_D = 1.759 \times 10^{-4}$$

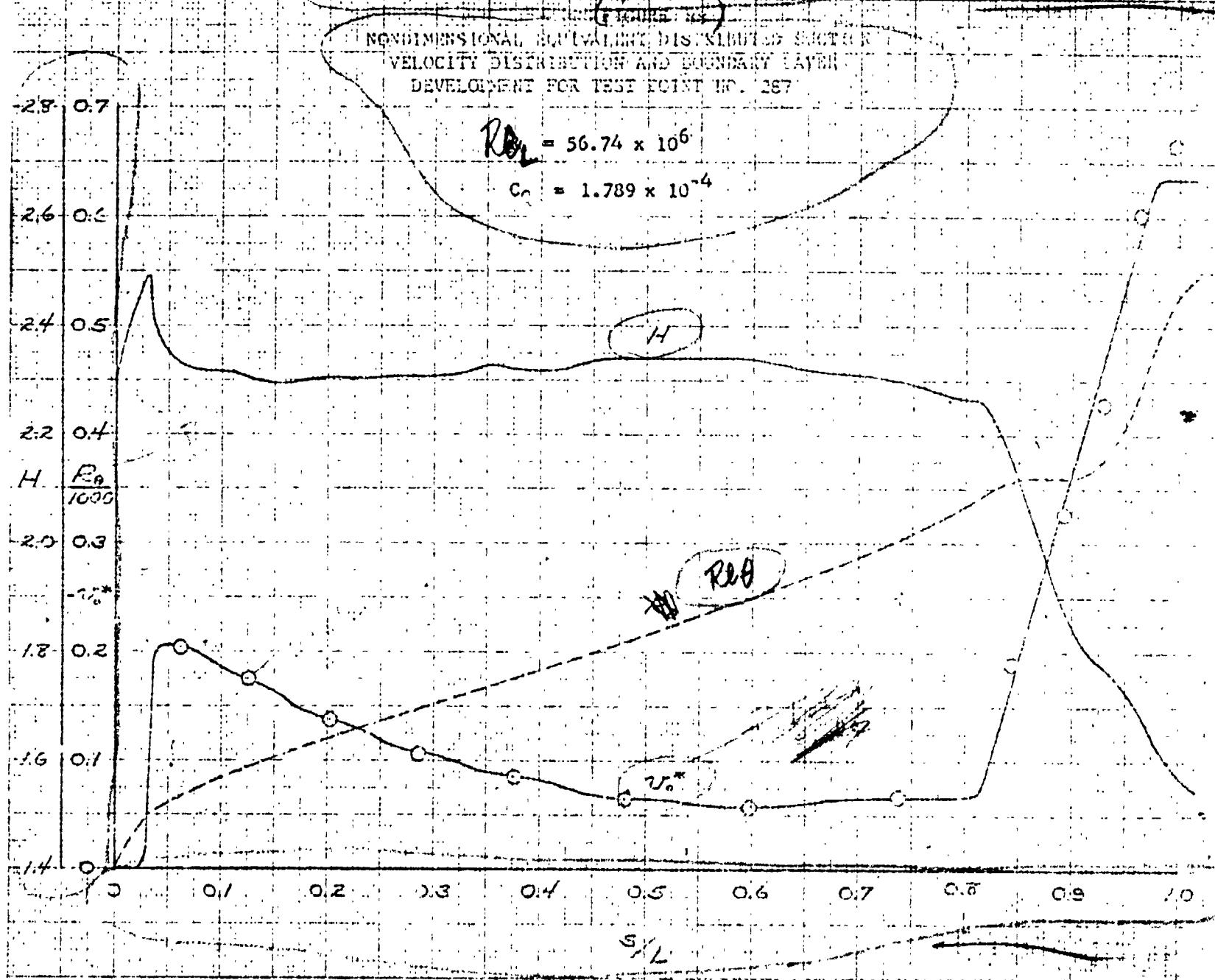


Richardt LFC body ($L/D = 8$)

NONDIMENSIONAL EQUIVALENT DISTRIBUTED SECTION
VELOCITY DISTRIBUTION AND BOUNDARY LAYER
DEVELOPMENT FOR TEST POINT NO. 287

$$Re = 56.74 \times 10^6$$

$$C_n = 1.789 \times 10^{-4}$$



Richardt LFC body ($4/D = 8$)

(FIGURE 54)

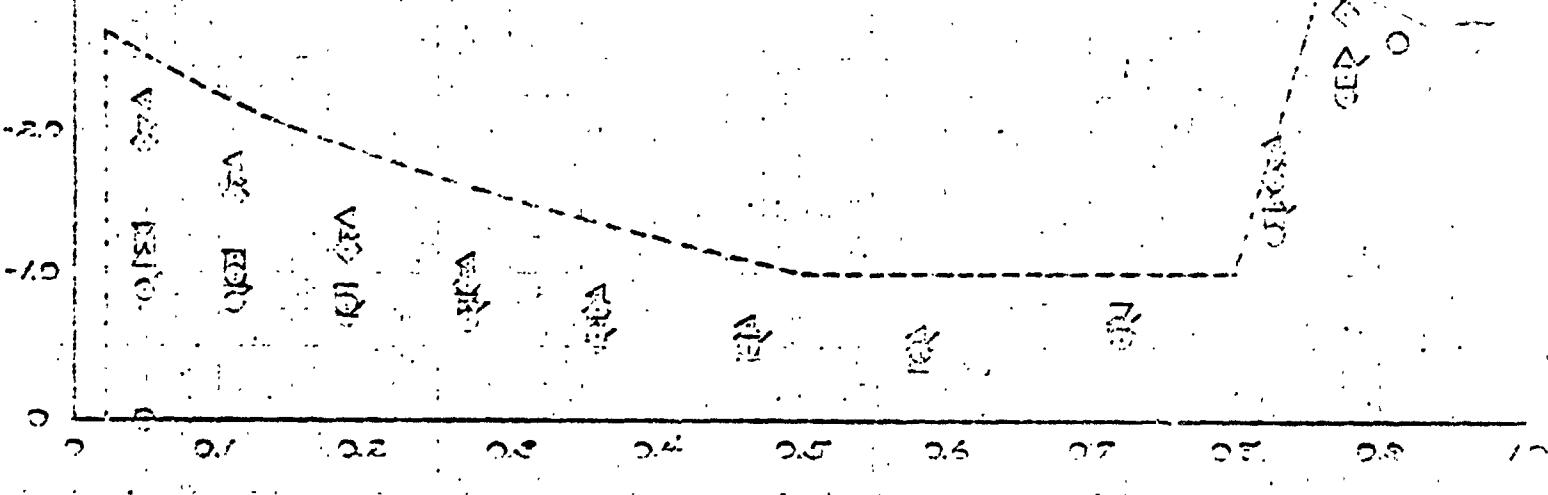
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LENGTHWISE DISTRIBUTION OF EQUIVALENT DISTRIBUTED

SUCTION VELOCITY v_0^* FOR SEVERAL REYNOLDS NUMBERS R_L

$R_L \cdot 10^{-6} \cdot 10^4 \cdot C_{L0}$ Wind Tunnel Pressure (Amer 12 ft tunnel)

SYN.	$R_L \cdot 10^{-6} \cdot 10^4 \cdot C_{L0}$	TESTS
O	17.11	2.05
X	22.17	1.87
□	30.24	1.72
△	50.45	2.01
◇	82.74	1.74
▽	46.05	1.72
▽	56.71	1.72
○	18.07	2.20
---	48.0	2.75 DESIGN



~~CONFIDENTIAL~~

NORTHERN CORPORATION

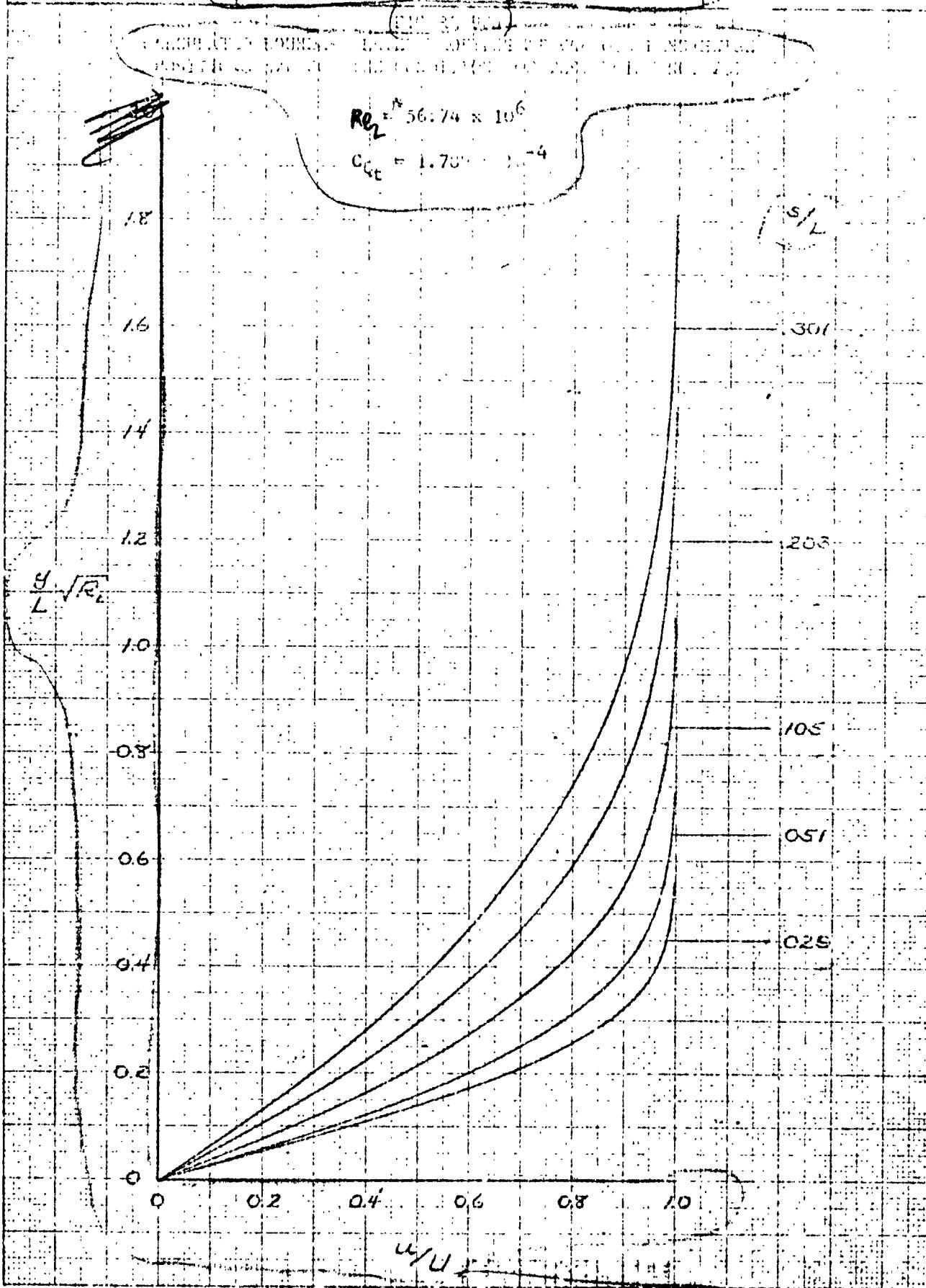
NORAIR DIVISION

CHECKED

REPORT NO.

DATE

MODEL

Richardt LFC body ($L/D=8$)

1000000000

INDUSTRIAL AERONAUTICS
TECHNICAL DIVISION

July 1963

Reichardt LFC body ($\frac{L}{D} = 8$)
($C_{dL} = 0$)

$Re_L = 56.74 \cdot 10^6$

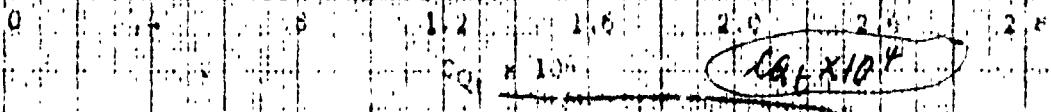
$\alpha = 0^\circ$

Reichardt LFC body ($\frac{L}{D} = 8$)

$$C_d = f(C_{dL}), \alpha = 0^\circ$$

$$Re_L = 56.74 \cdot 10^6$$

$C_{dL} \text{ vs } C_{dW} \times 10^4$



July 1963

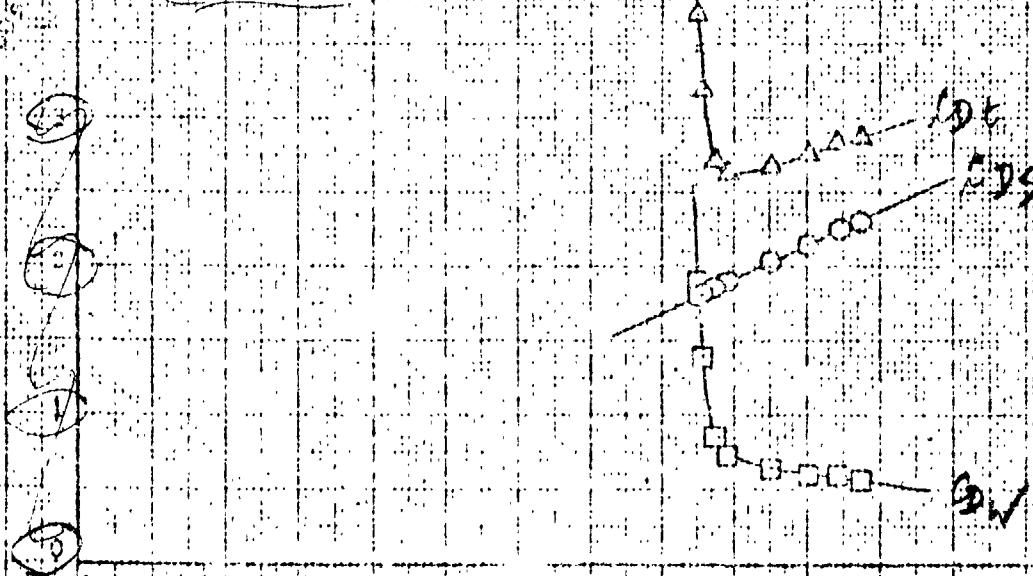
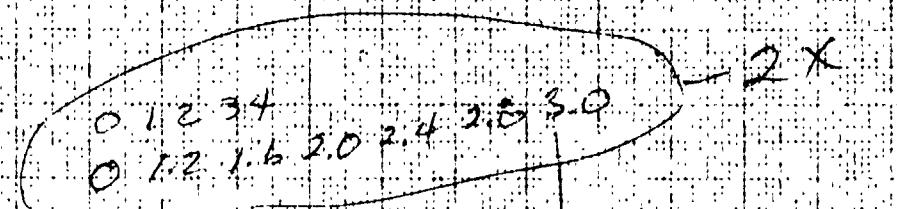
Reichardt LFC body ($\frac{L}{D} = 8$)
($c_{\text{L}} = 0.45$)

R_{L} 5571.106

0°

Reichardt LFC body ($\frac{L}{D} = 8$)

$S = f(c_{\text{L}})$, ~~$R_L = 5571.106$~~



Cost, CAV, CAV * 10

10

$c_L \times 10^{-4}$

July 1963

MONTE CARLO SIMULATION

Richardt LFC body ($\frac{L}{D} = 8$)
($Re = 28$)

DATA FROM CFD ANALYSIS FOR MACH 0.8

FRONTSIDE

Re

$Re = 31.15 \times 10^6$

$\alpha = 0^\circ$

α_{deg}

10

20

30

40

50

60

70

80

90

100

110

120

130

140

150

160

170

180

190

200

Fig. 25. 48, 49, and 50 sheet
one with 100 as angle
scale

$C_D \times 10^6$

0.2

0.4

0.6

0.8

1.0

1.2

1.4

1.6

1.8

2.0

2.2

2.4

2.6

2.8

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51.2

51.4

REVIEWED

. Gross

**NORTHROP CORPORATION
NORAIR DIVISION**

8-3
REPORT TO:
NO: 5-44 (B.I.C.)
MONEY

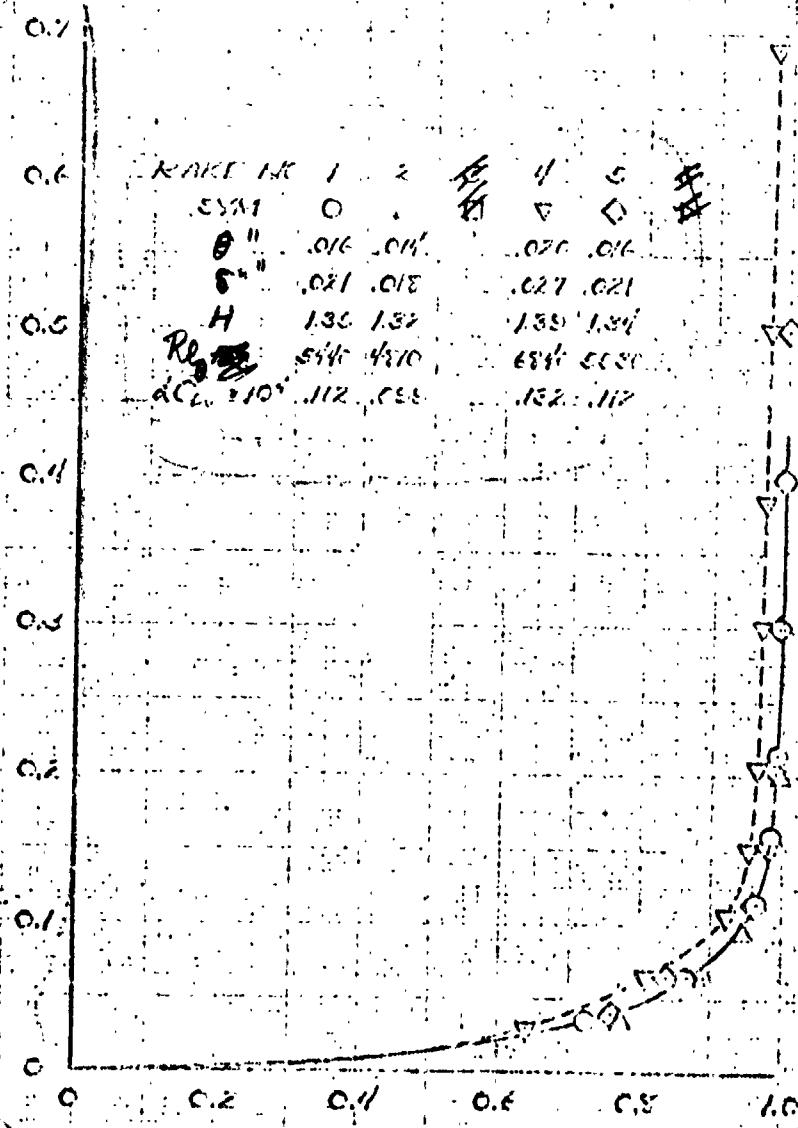
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July 1963

BOUNDARY LAYER VELOCITY PROFILES AS MEASURED

AT THE AFT END OF THE C. L.

Run No. 237

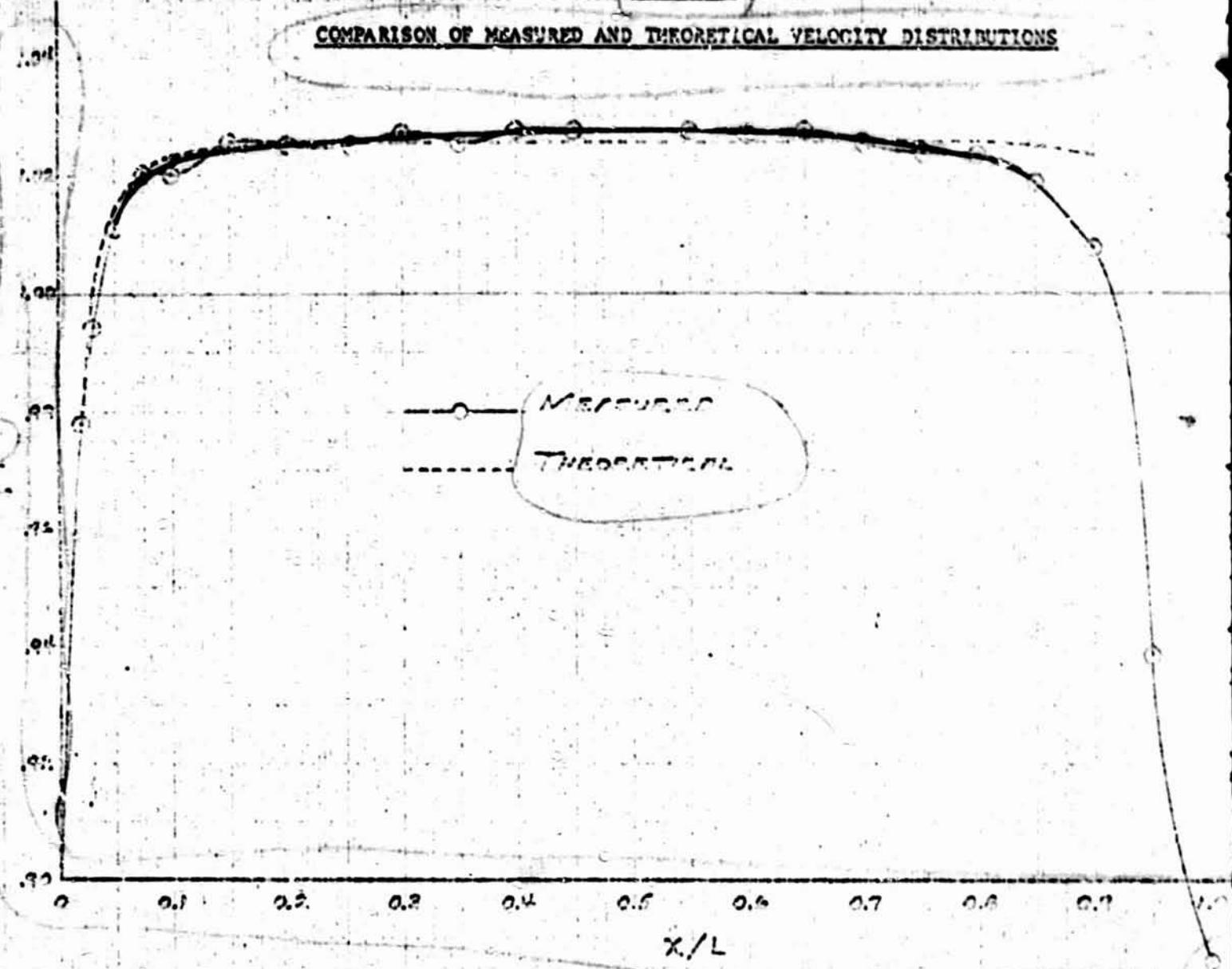


~~CONFIDENTIAL~~

Berchardt LFC body ($L/D = 8$)

(FIGURE 5)

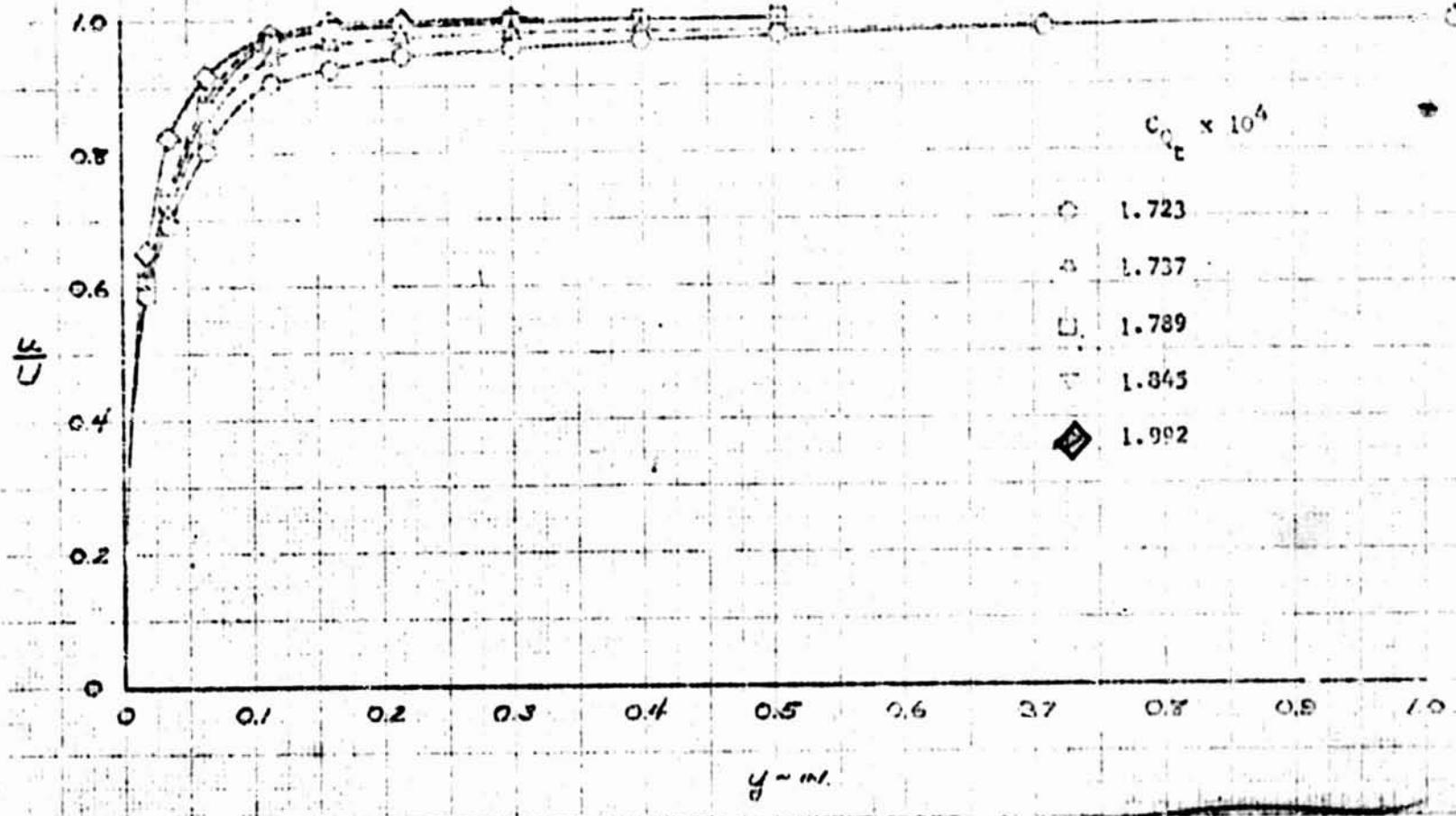
COMPARISON OF MEASURED AND THEORETICAL VELOCITY DISTRIBUTIONS

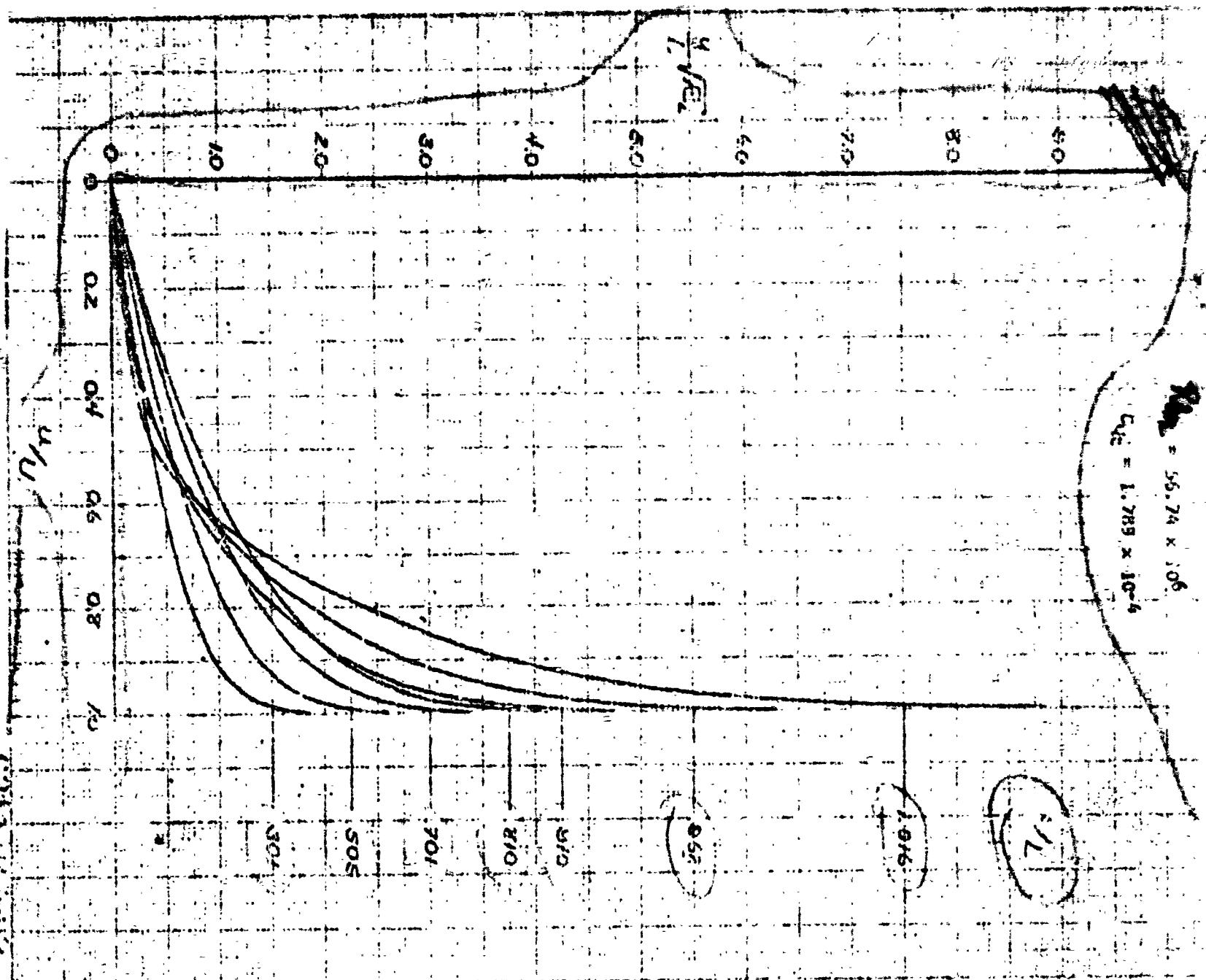


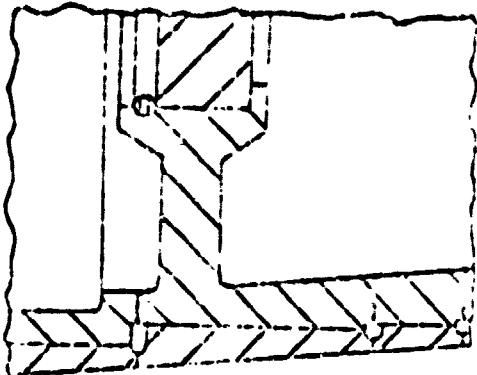
Reichardt LFC theory ($L/D = 8$)

(1956, 1958)
VARIATION OF AFT END PRESSURE DENSITY WITH UV
PROFILES WITH EQUATION AND PICTURE

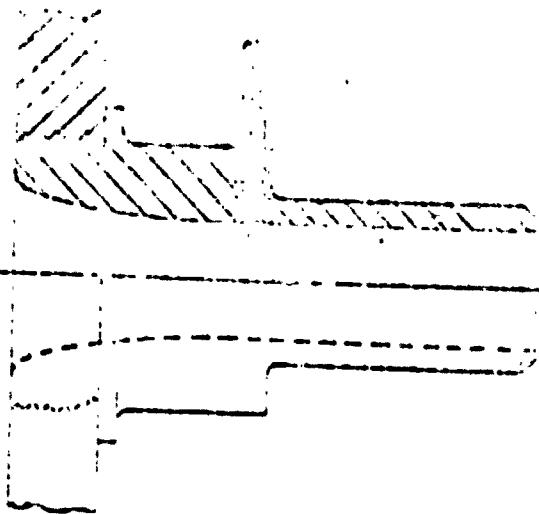
$$Re = 56,740 \times 10^6$$





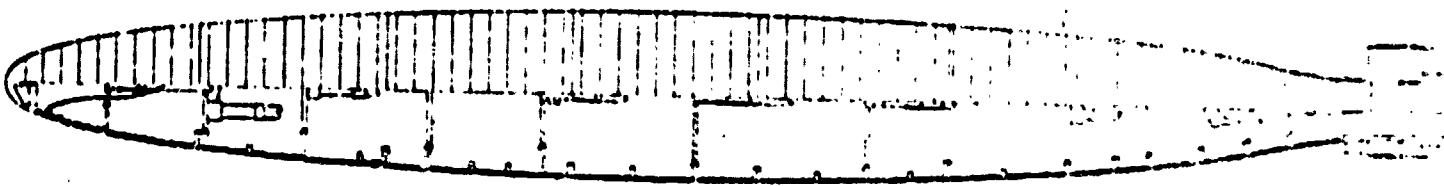


Schematic View Showing Typical Bulkhead Installation and Details of Suction Slot, Plenum Chamber and Suction Flow Metering Holes



Schematic View of Typical Flow Measuring Nozzle Installation

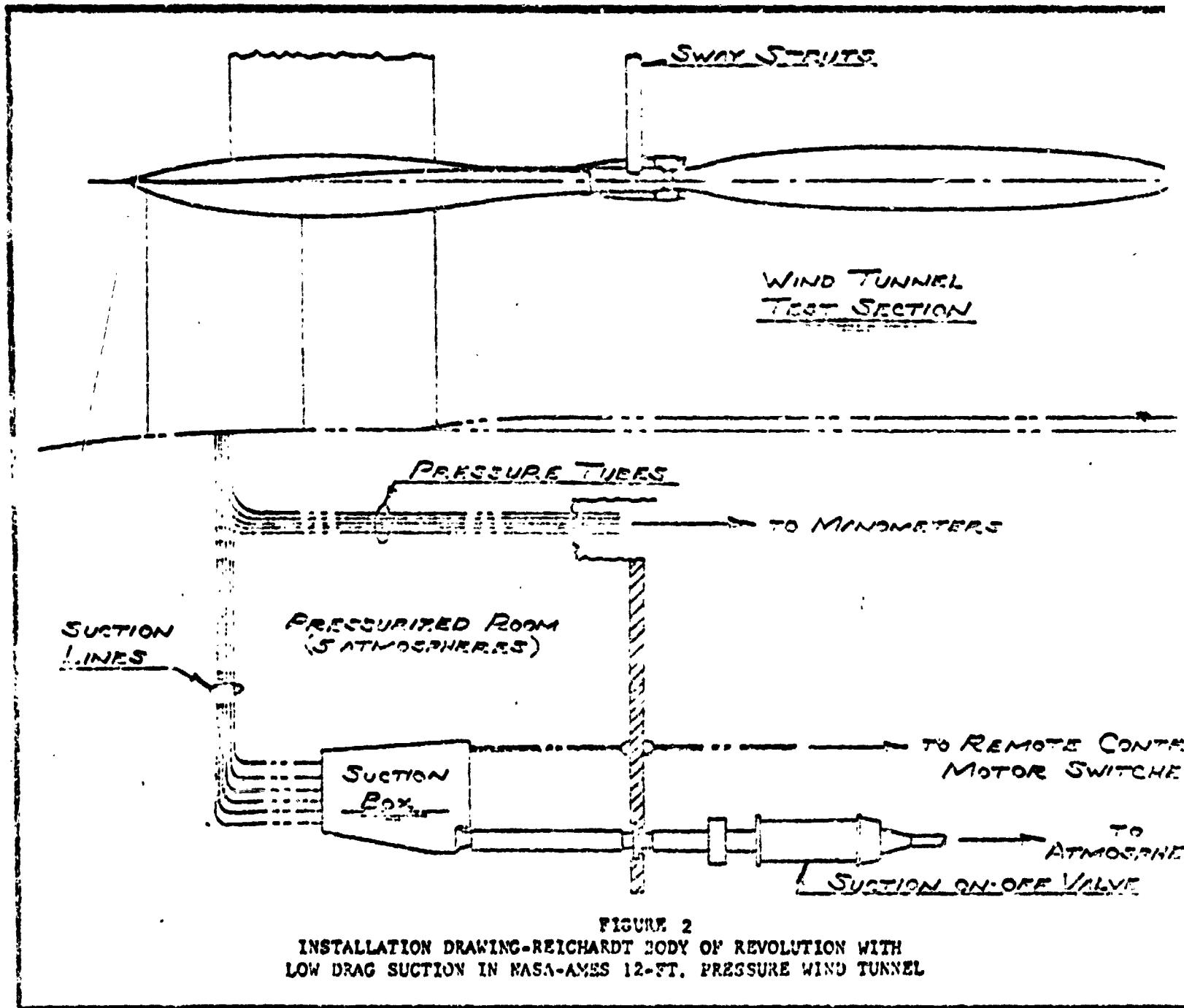
Reichardt Absaugrotationskörper ($L/D = 8$) mit Absehung durch 11% Schlitze



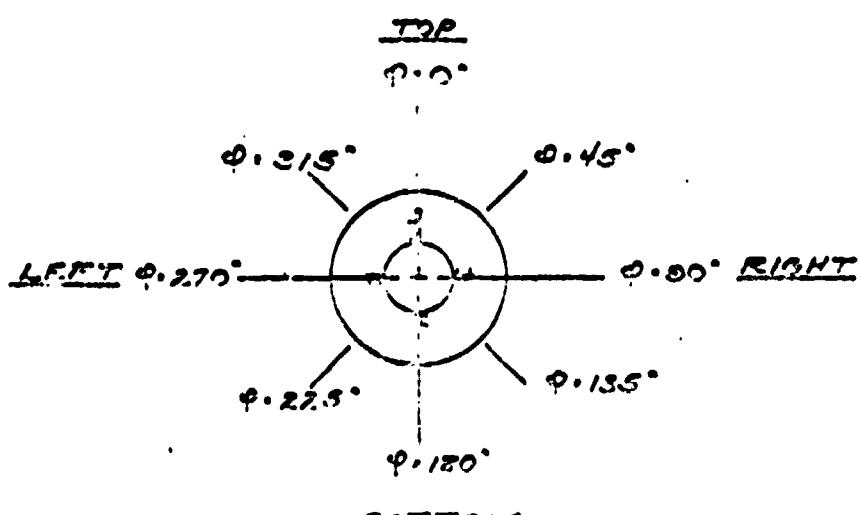
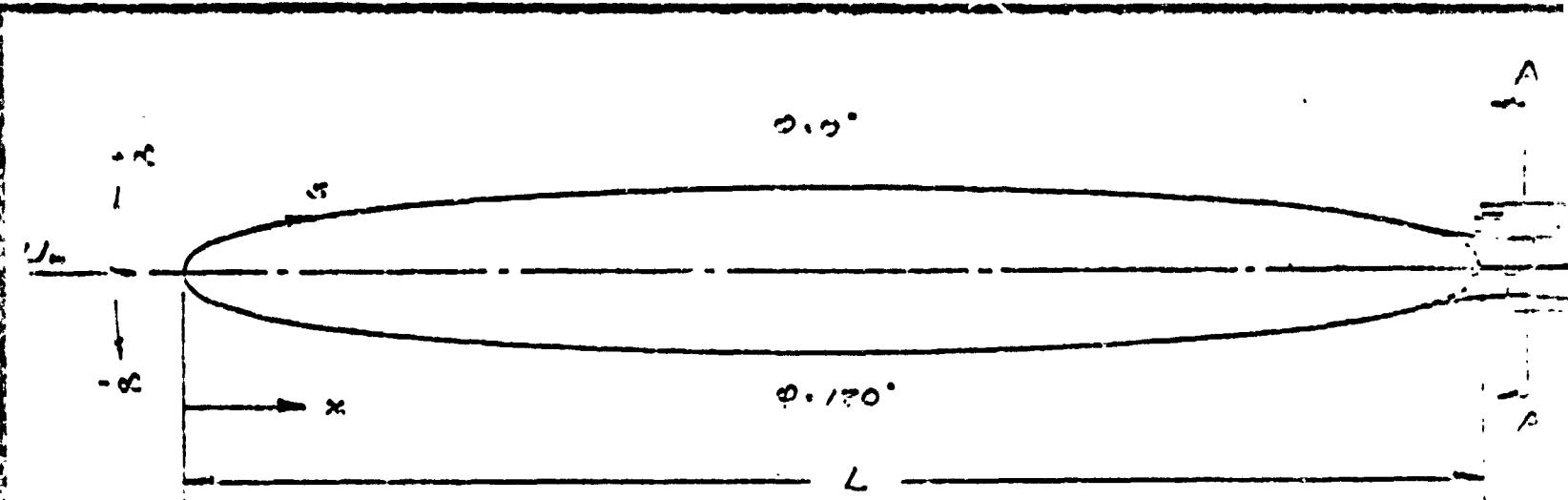
Höhe $l = 12.5^{\circ}$
Durchmesser $D = 15.5^{\circ}$
Schlitze ≈ 0.003

MODEL CROSS SECTION WITH DETAILS OF SUCTION SLOTS

ref. 1 --



REICHARDT BODY OF REVOLUTION WITH LOW DRAG SUCTION IN NASA-AMES 12-FOOT PRESSURE WING TUNNEL
FIGURE 3



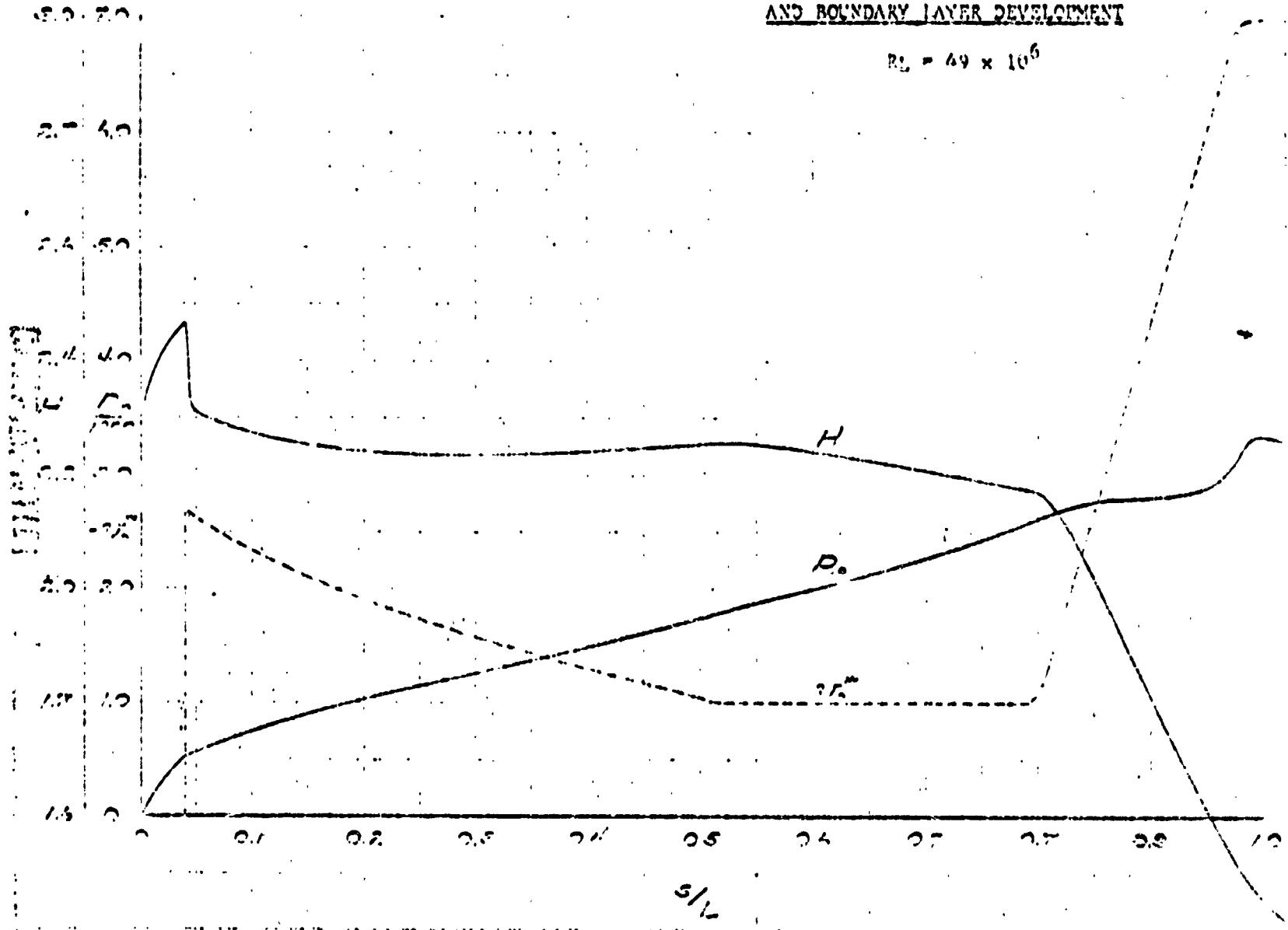
VIEW A-A

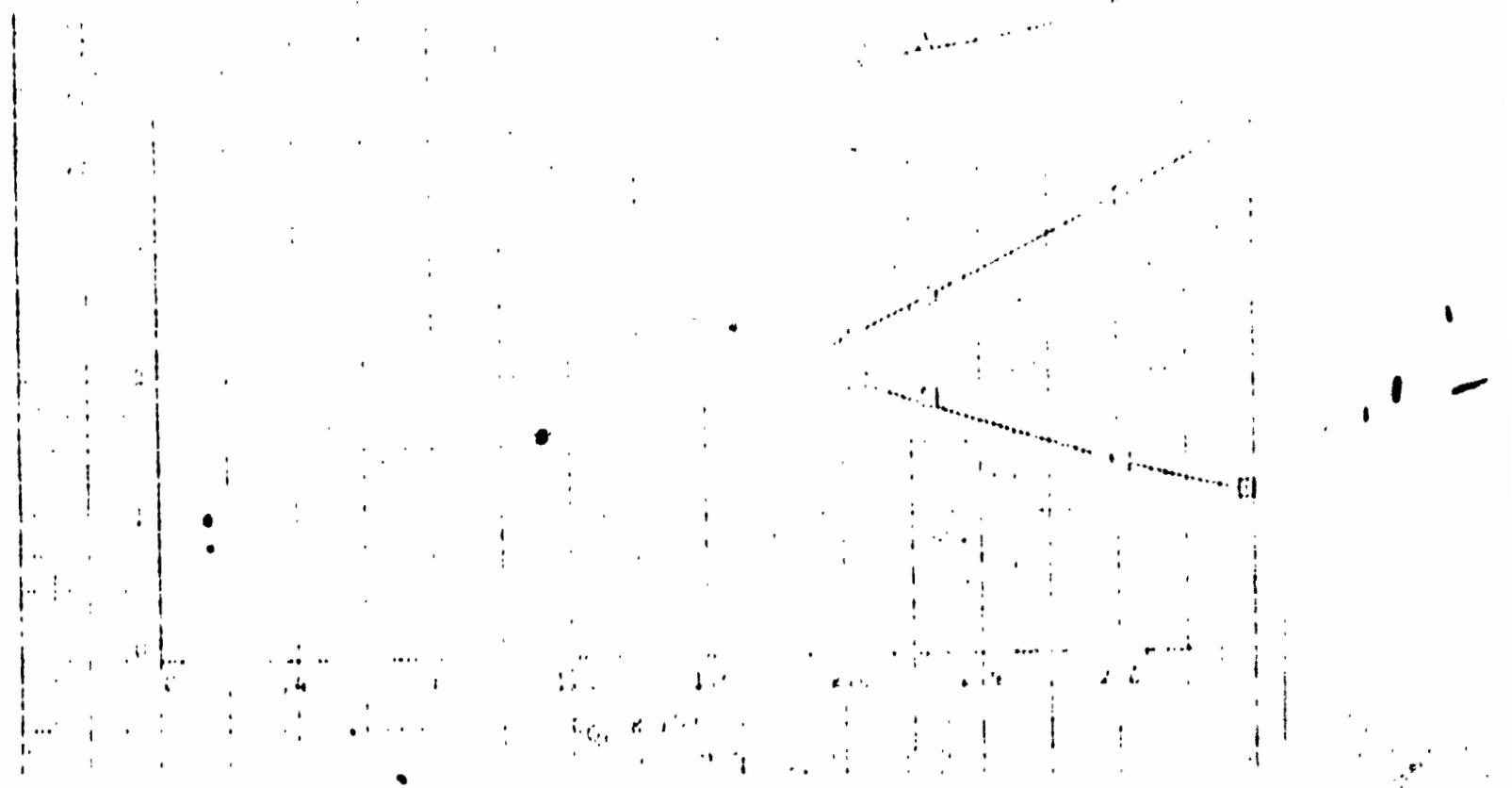
FIGURE 4
COORDINATE SYSTEM

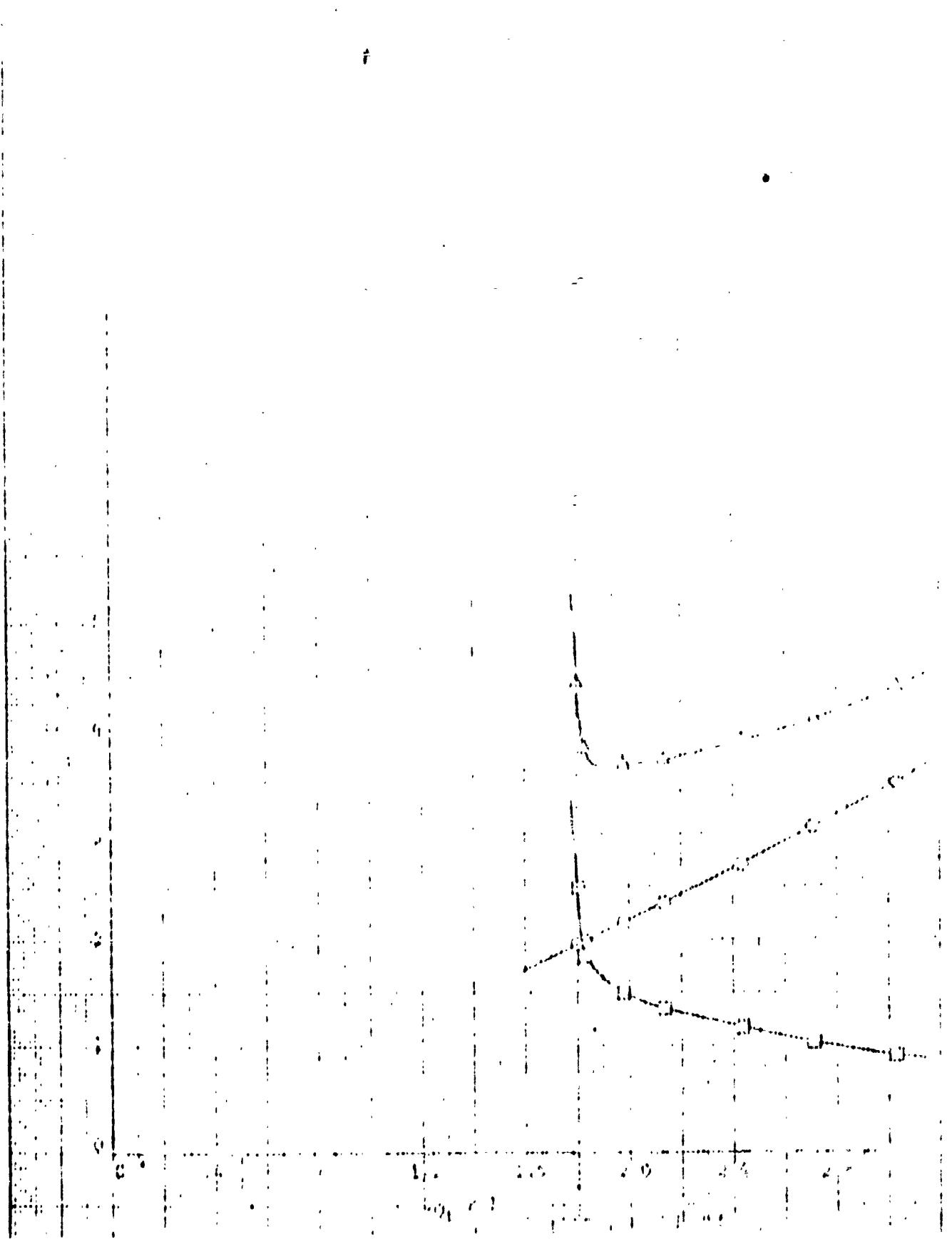
FIGURE 6
DESIGN SUCTION VELOCITY DISTRIBUTION

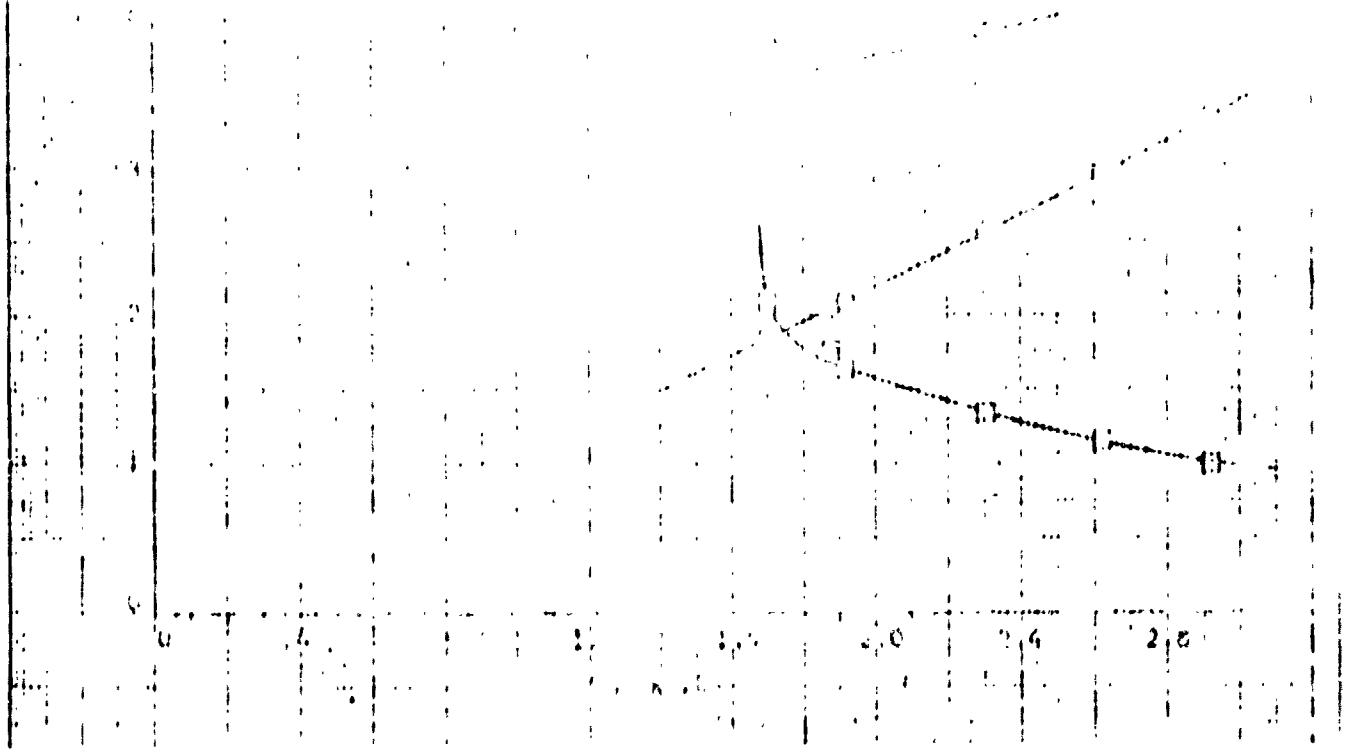
AND BOUNDARY LAYER DEVELOPMENT

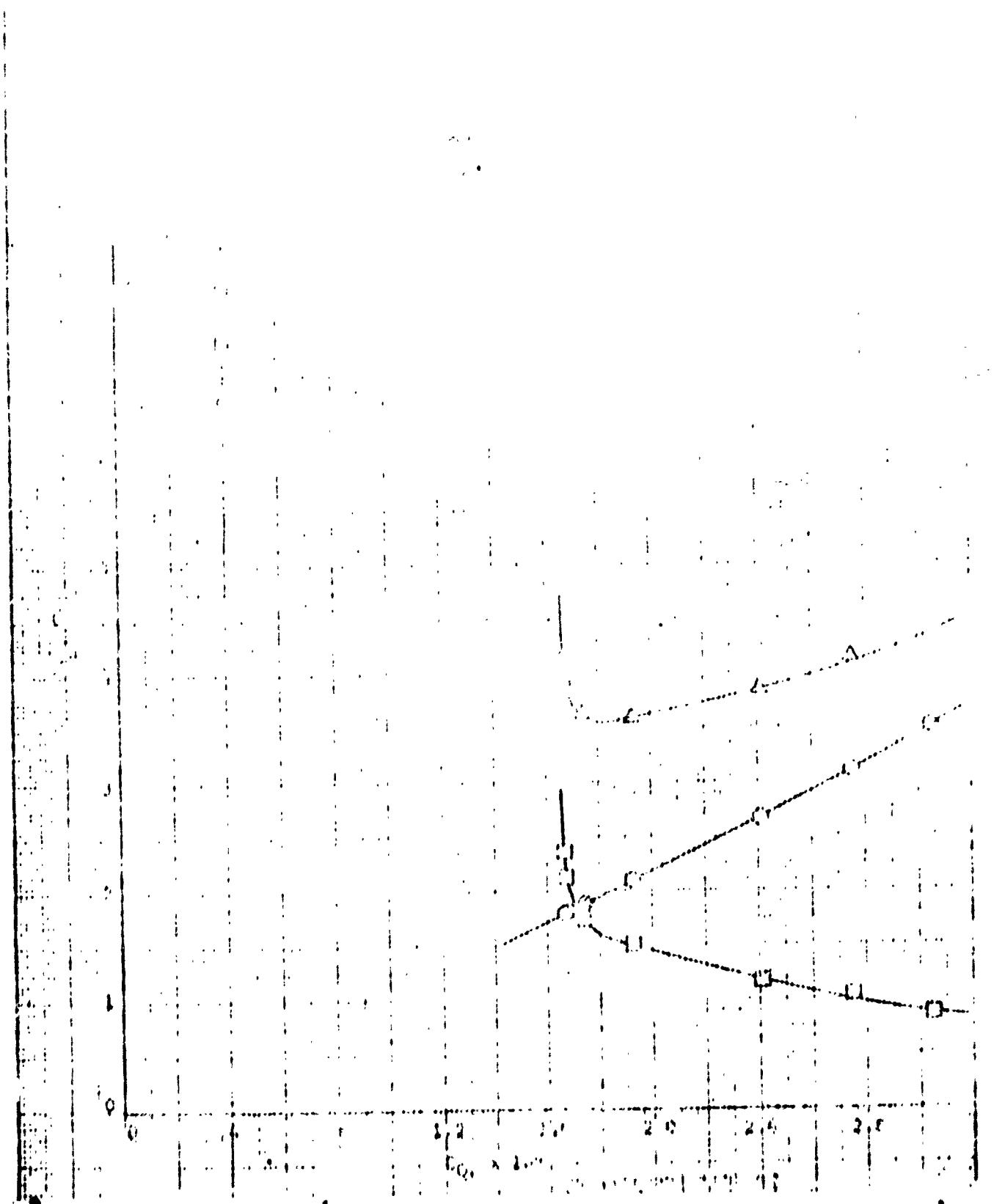
$$R_L = 49 \times 10^6$$

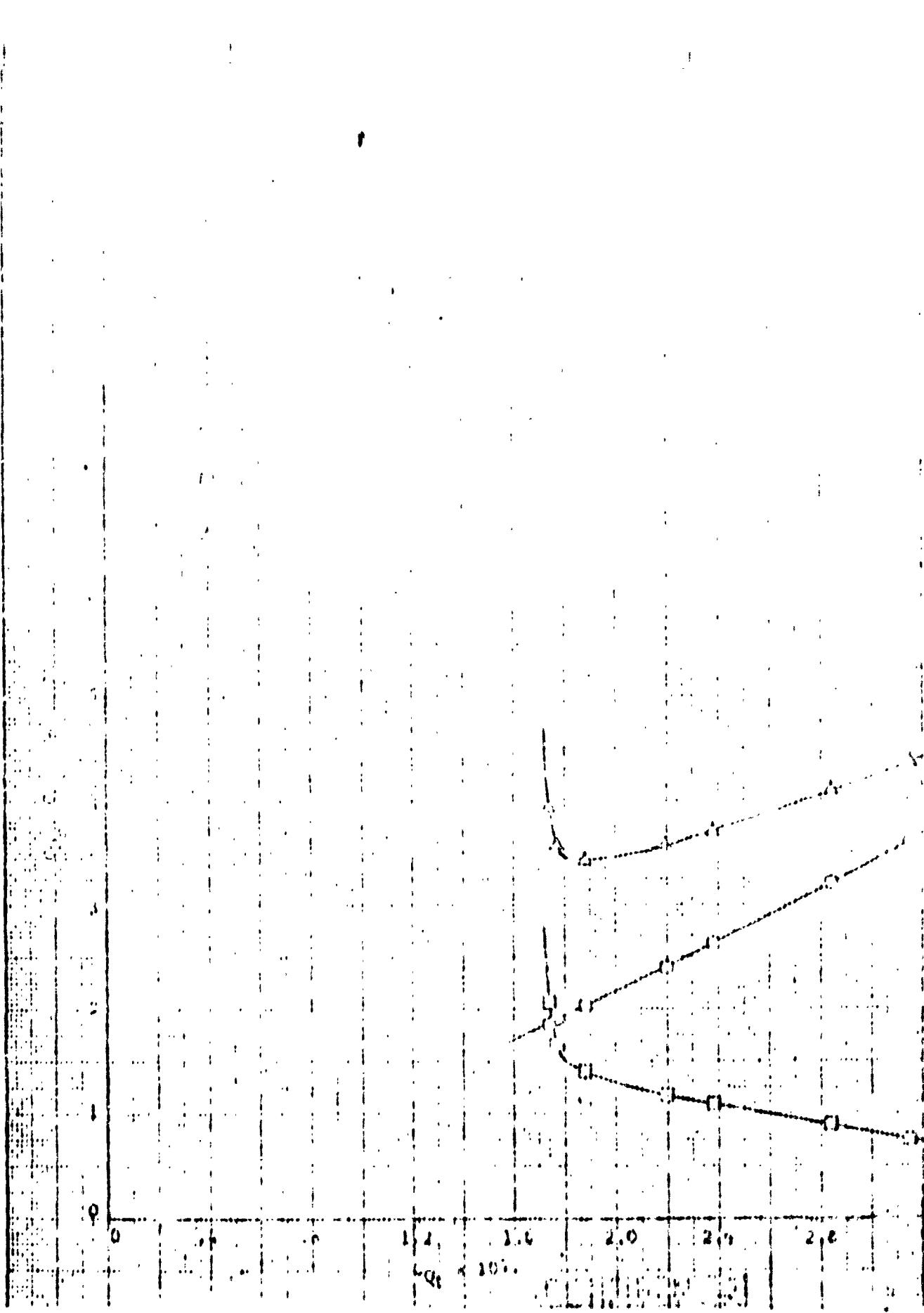


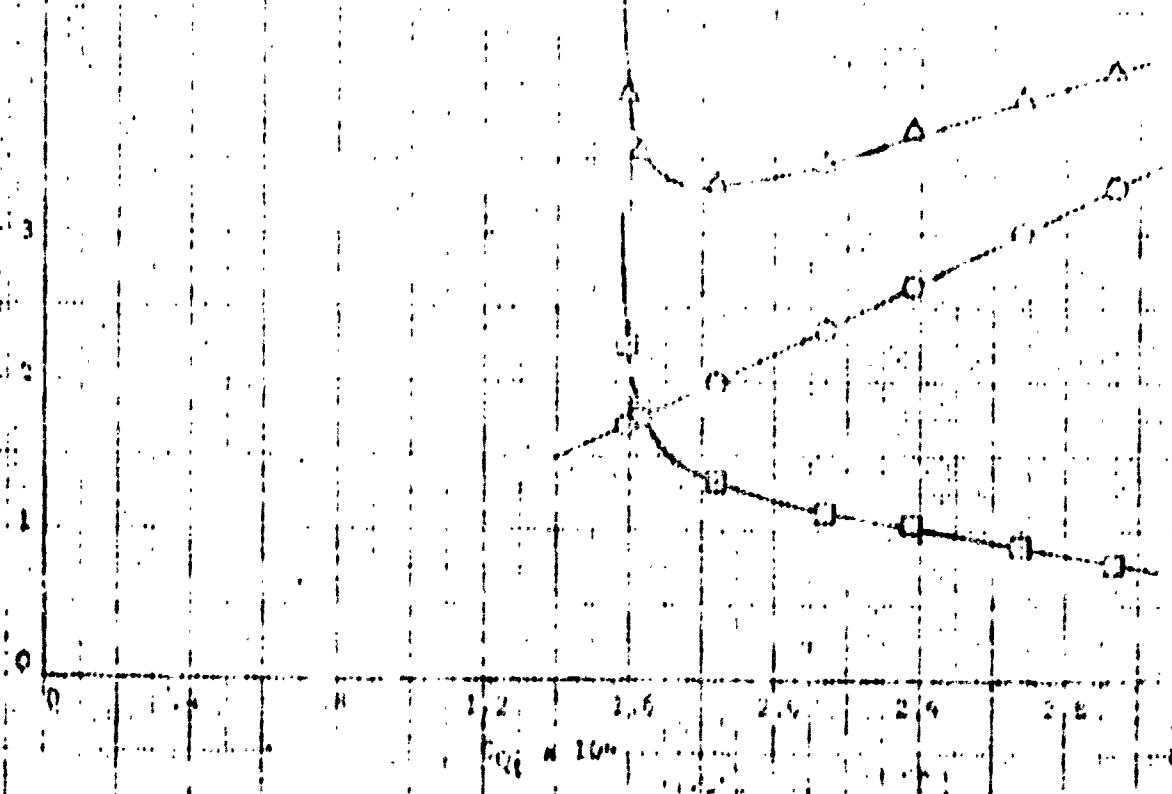








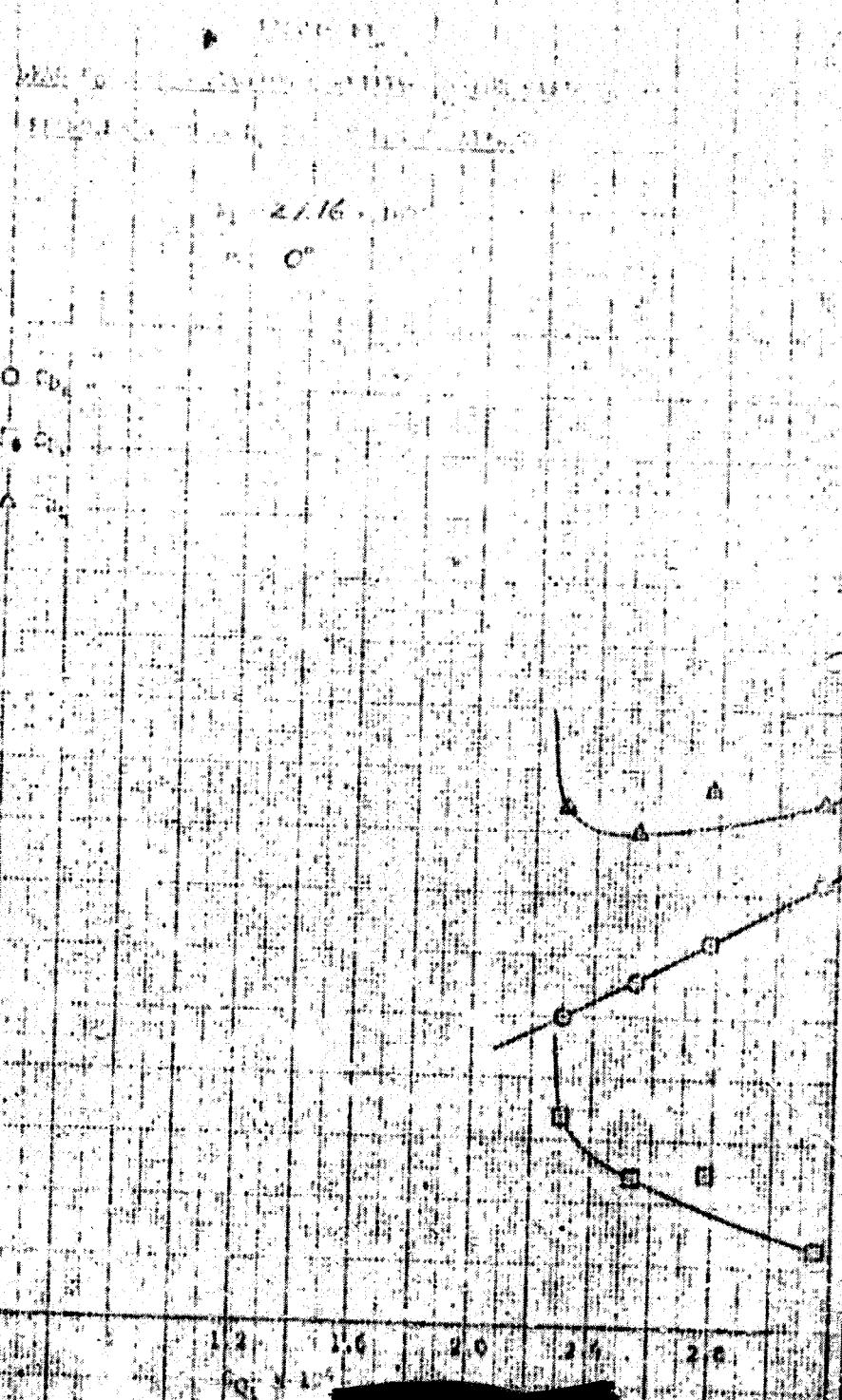


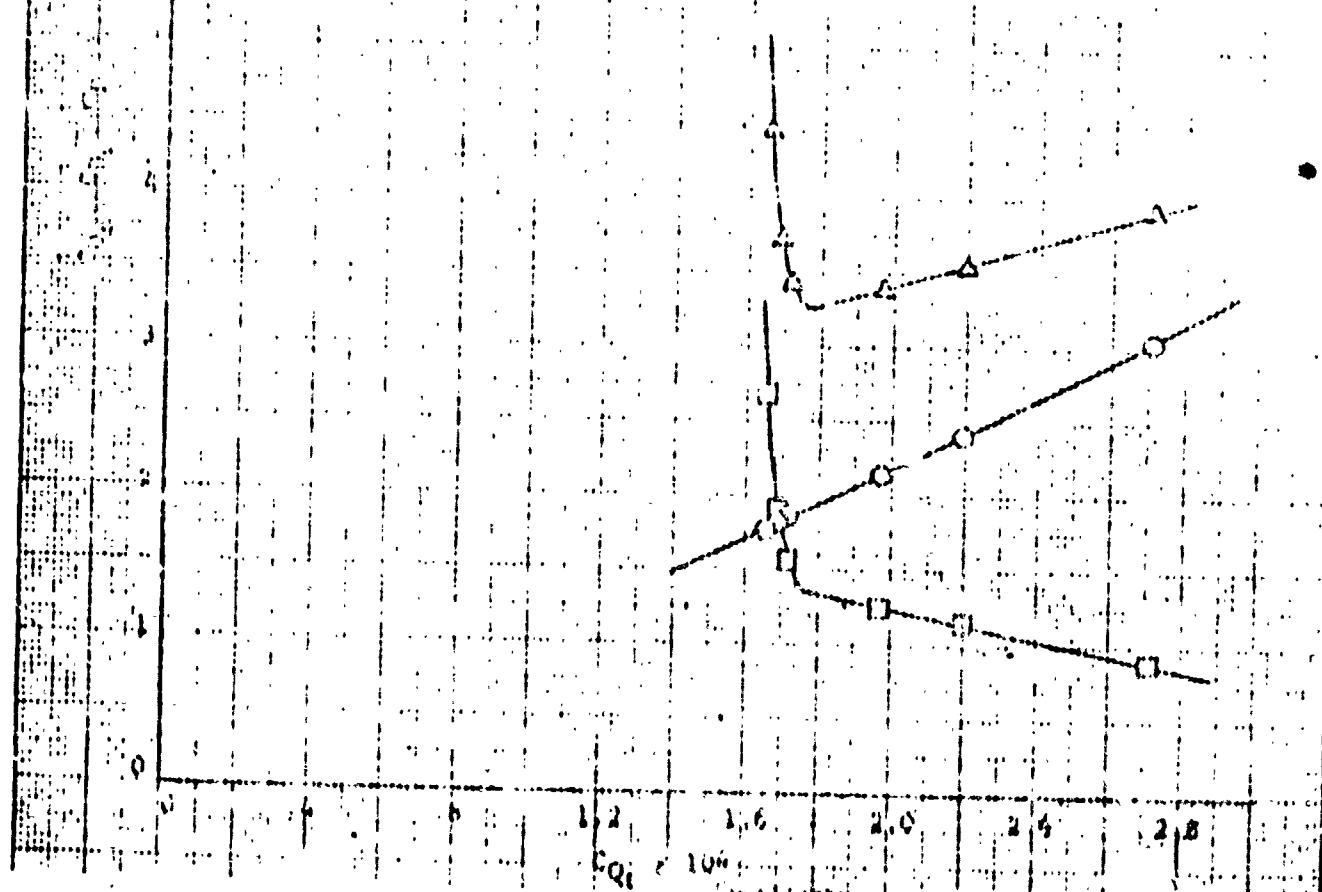


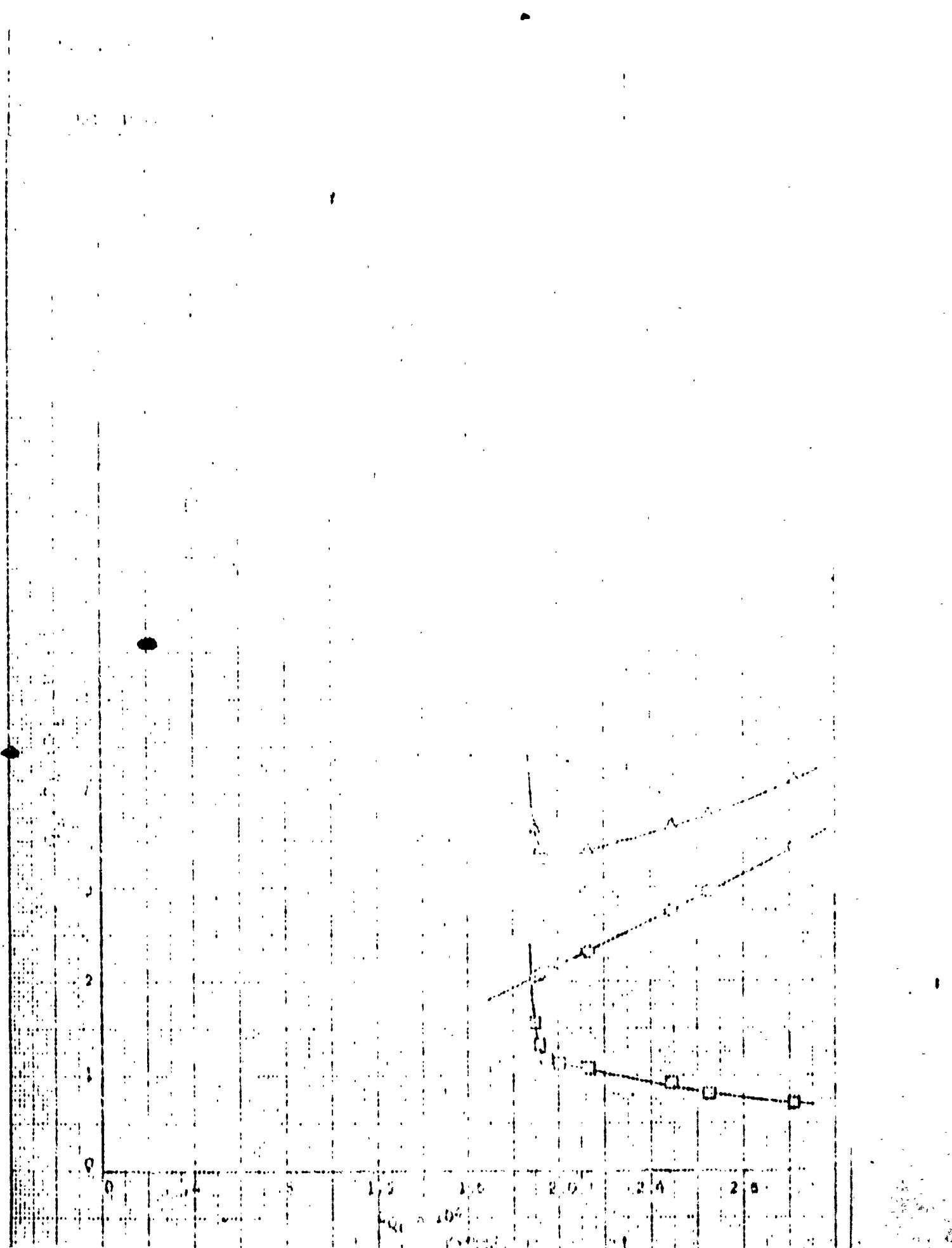
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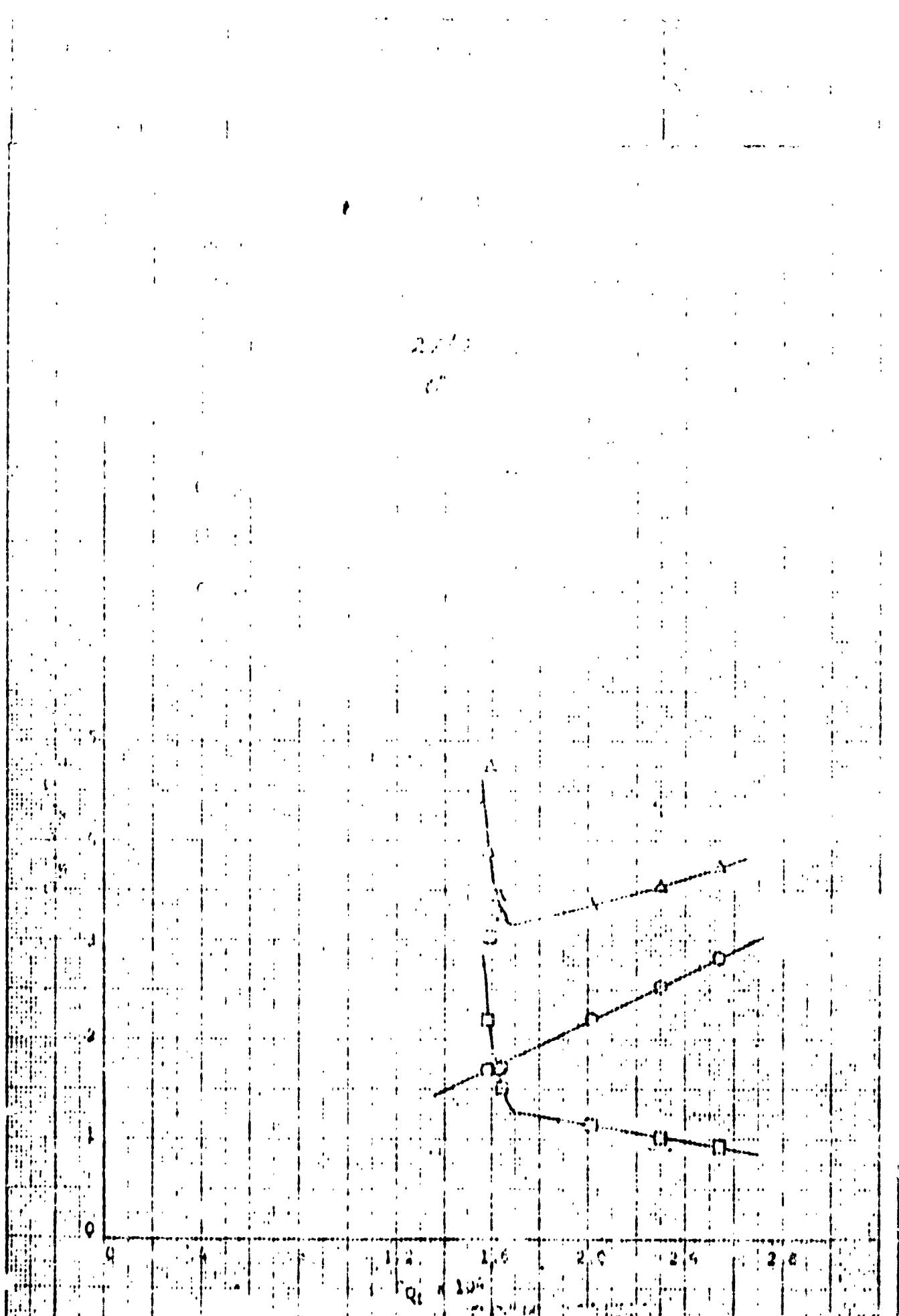
The right connection

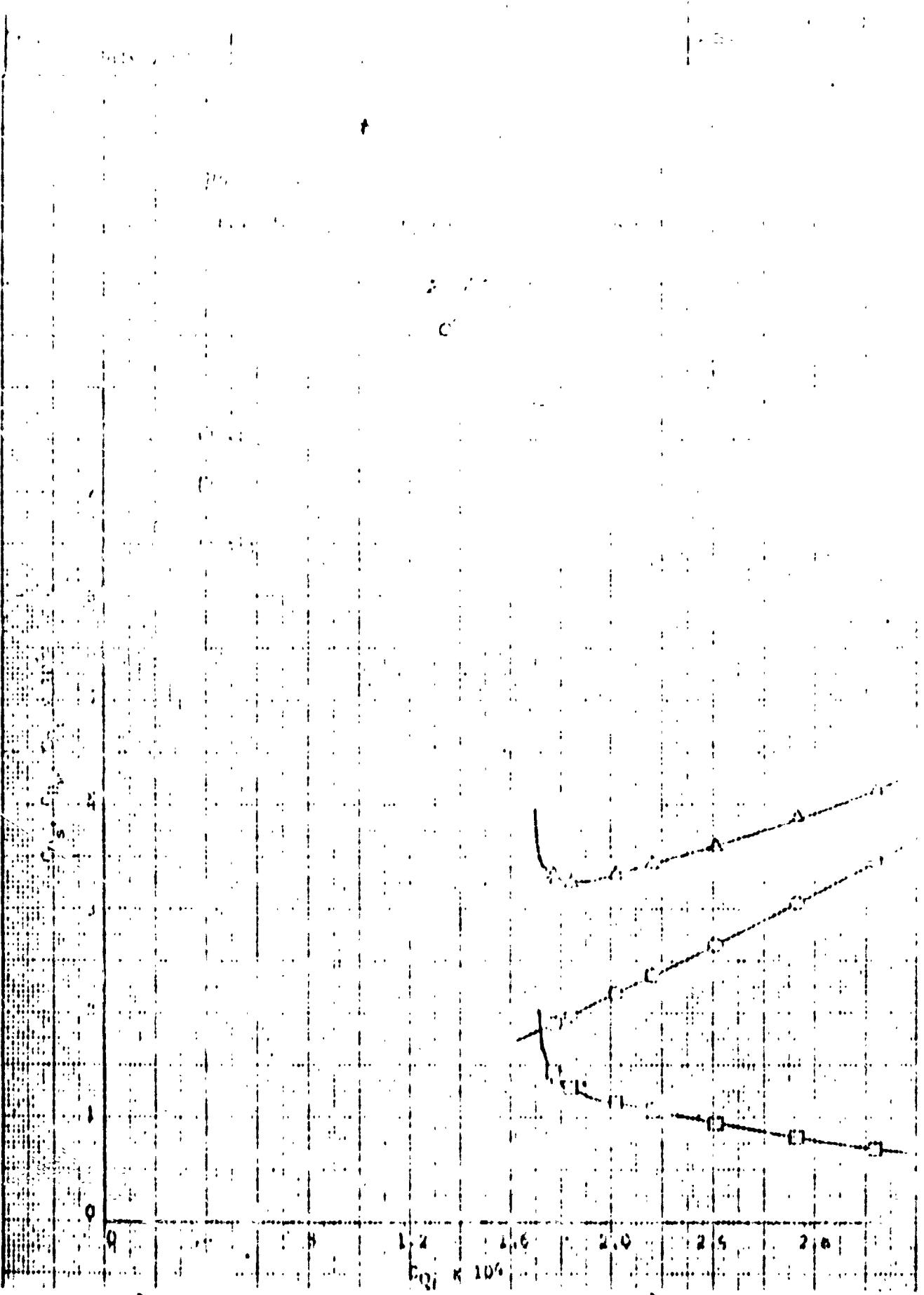
Digitized by srujanika@gmail.com

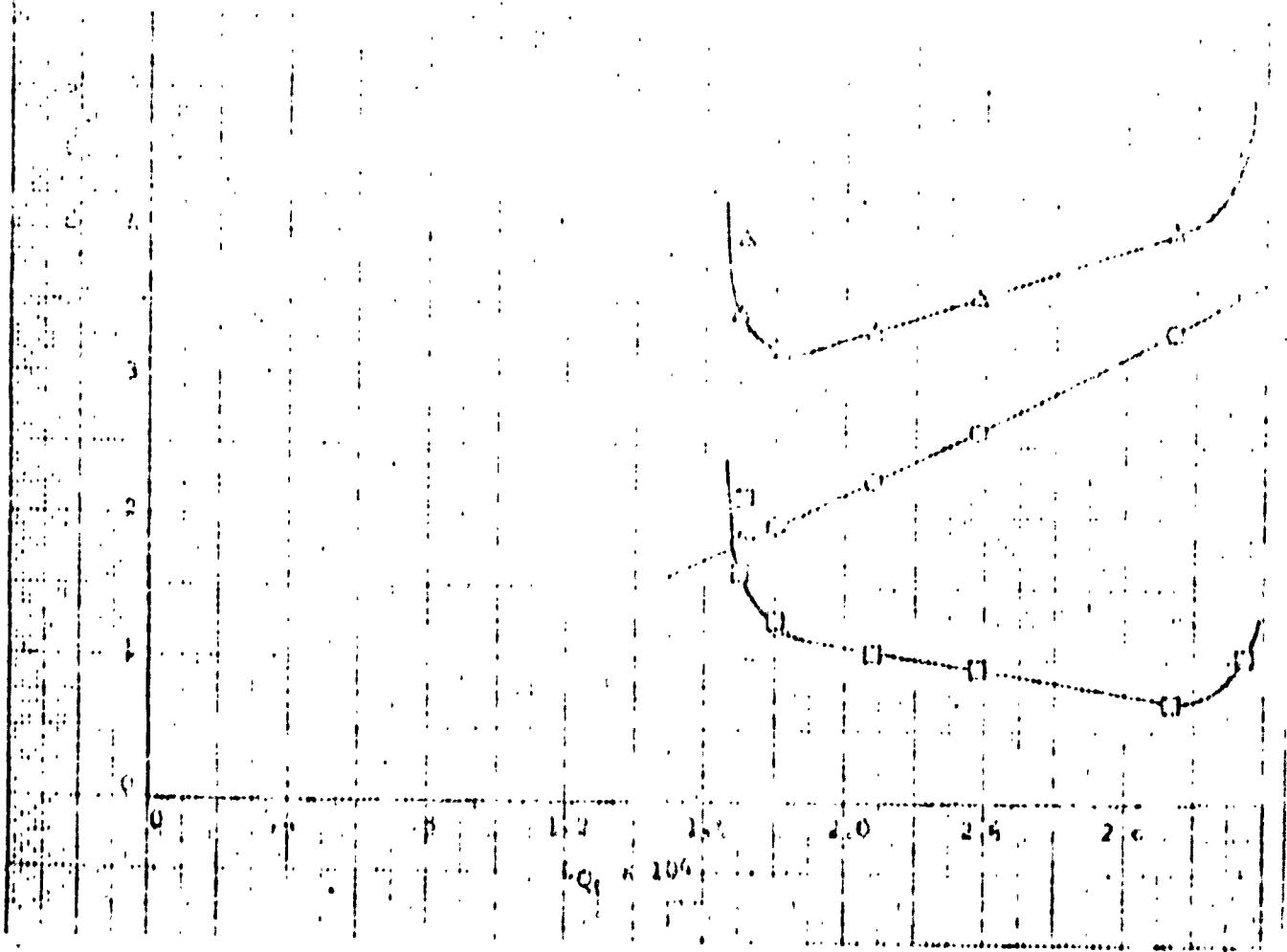


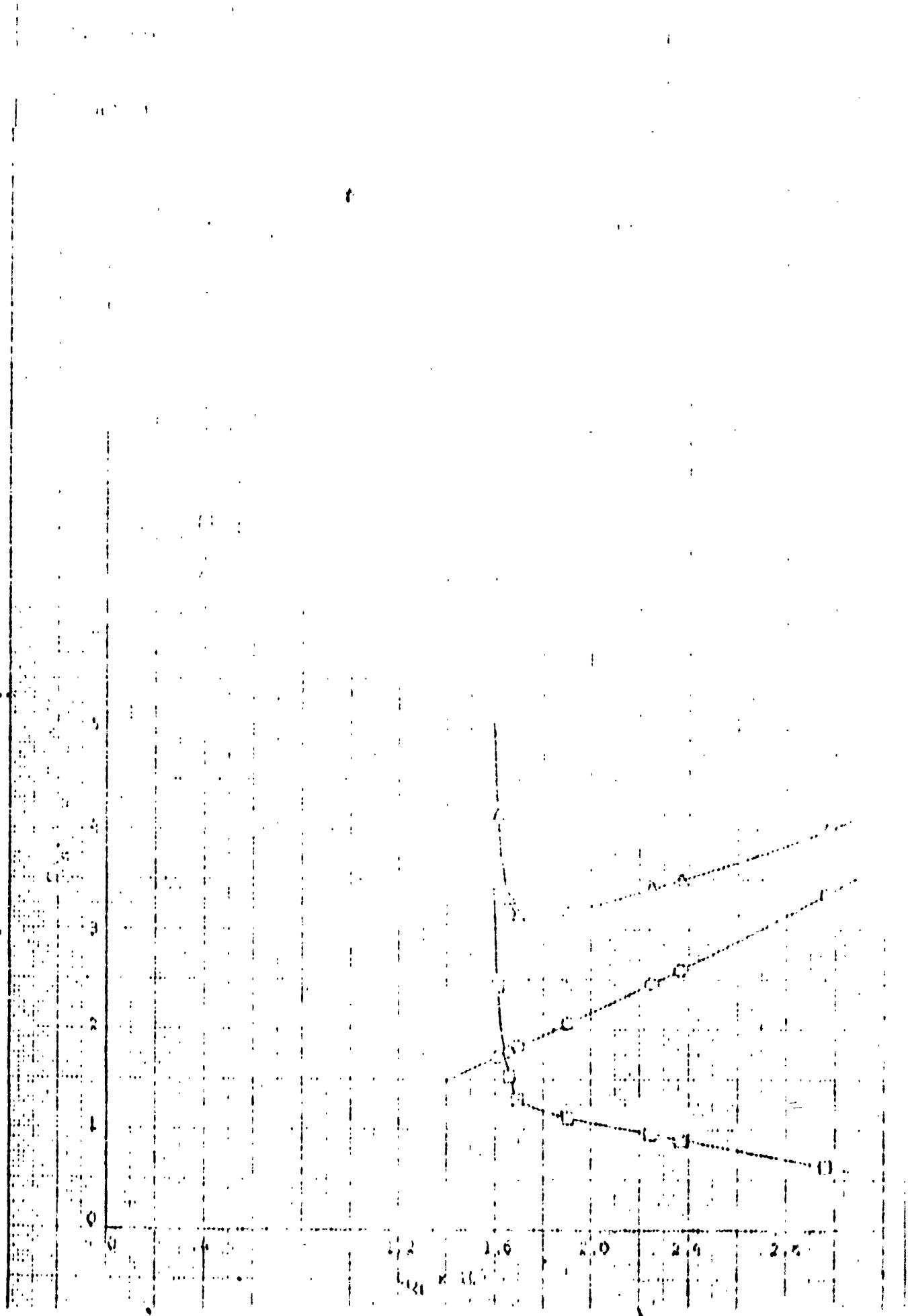


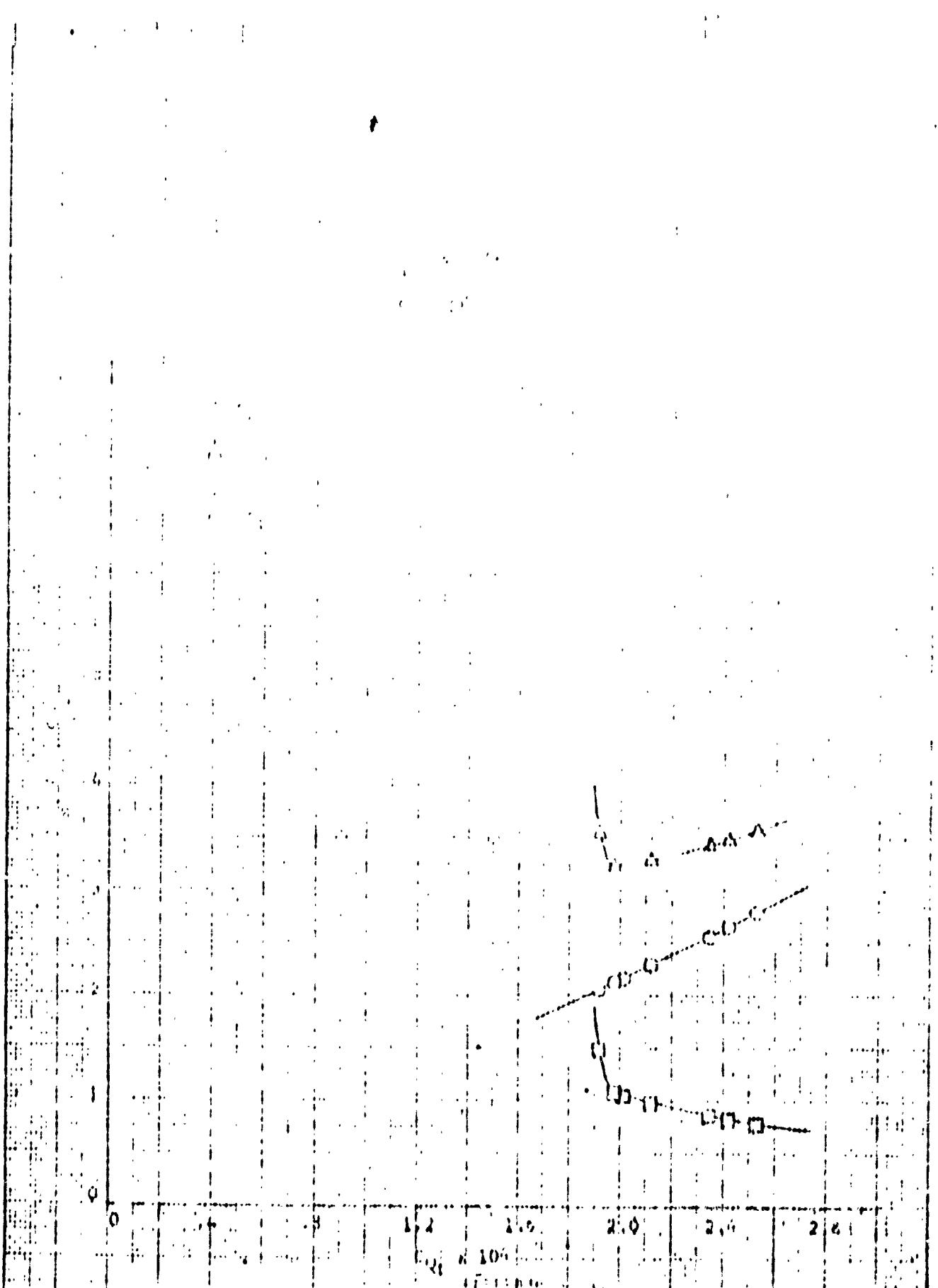


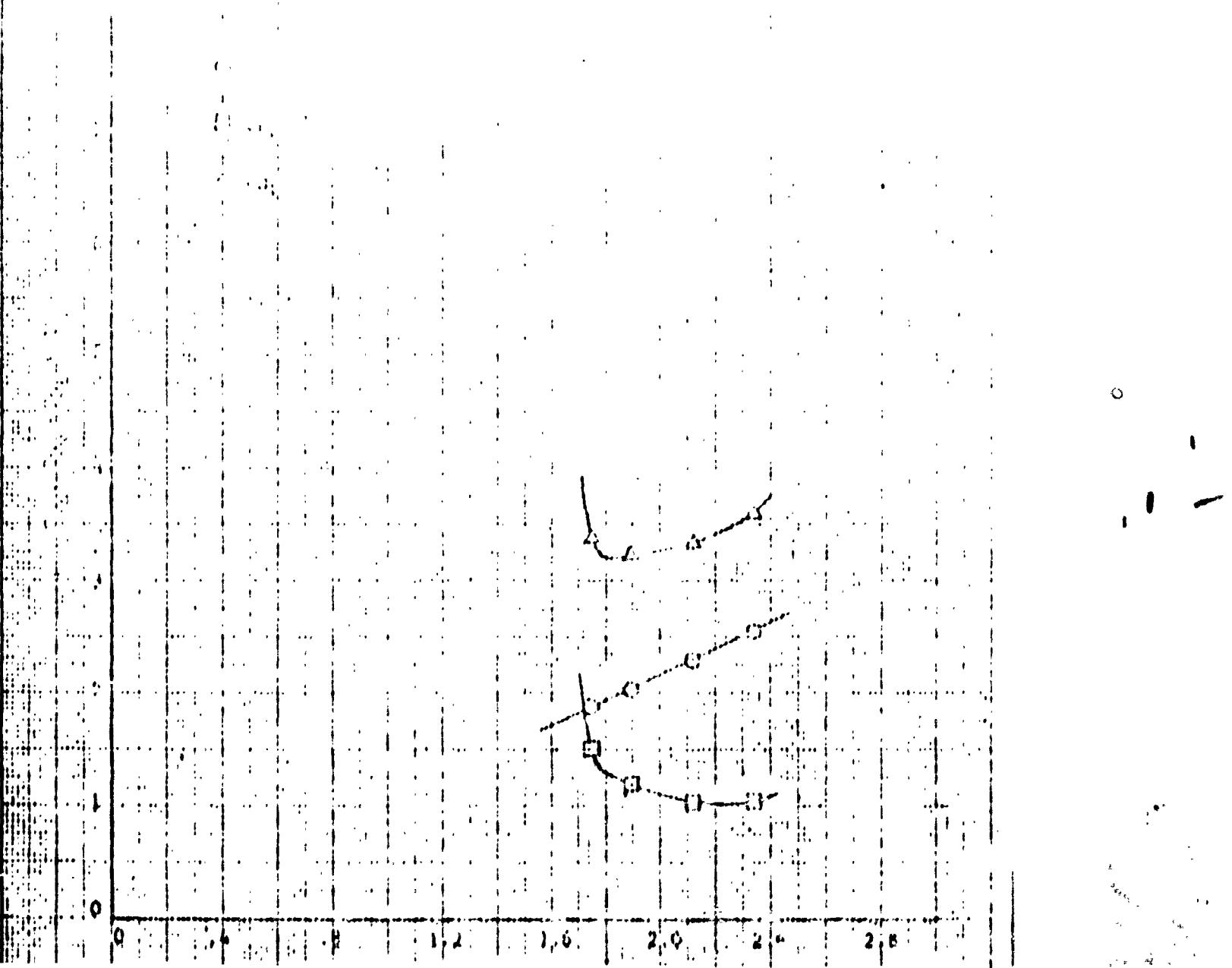


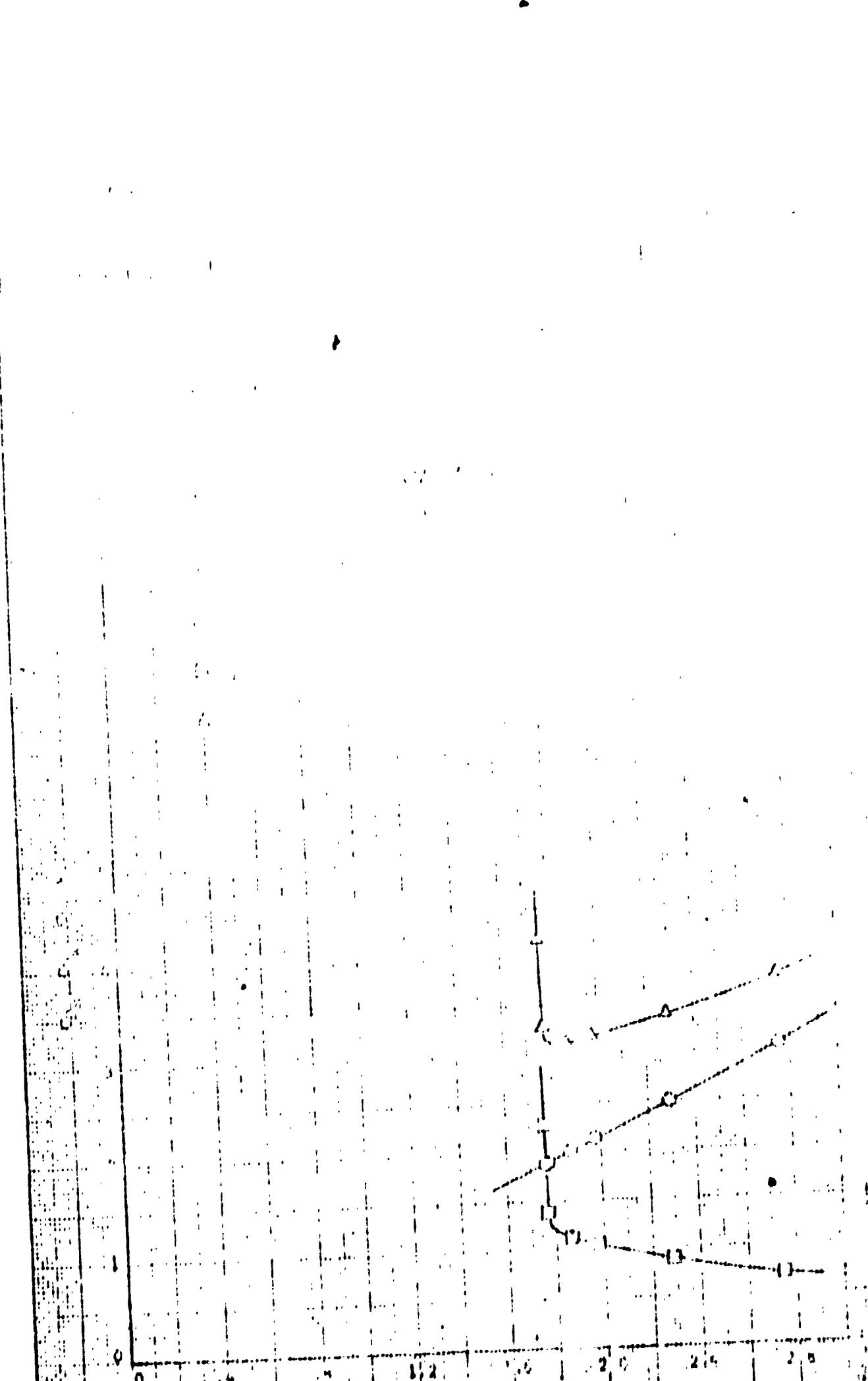


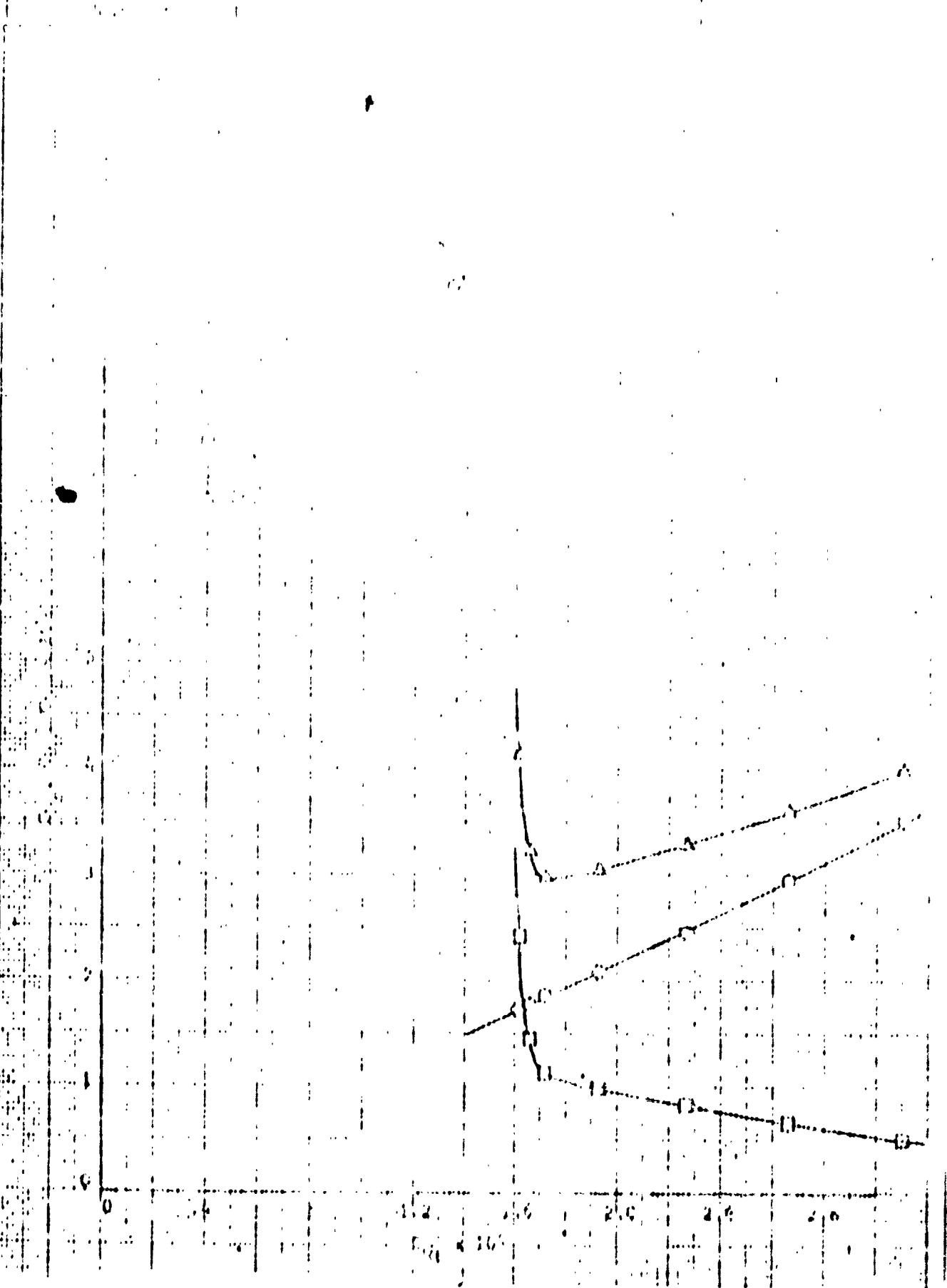










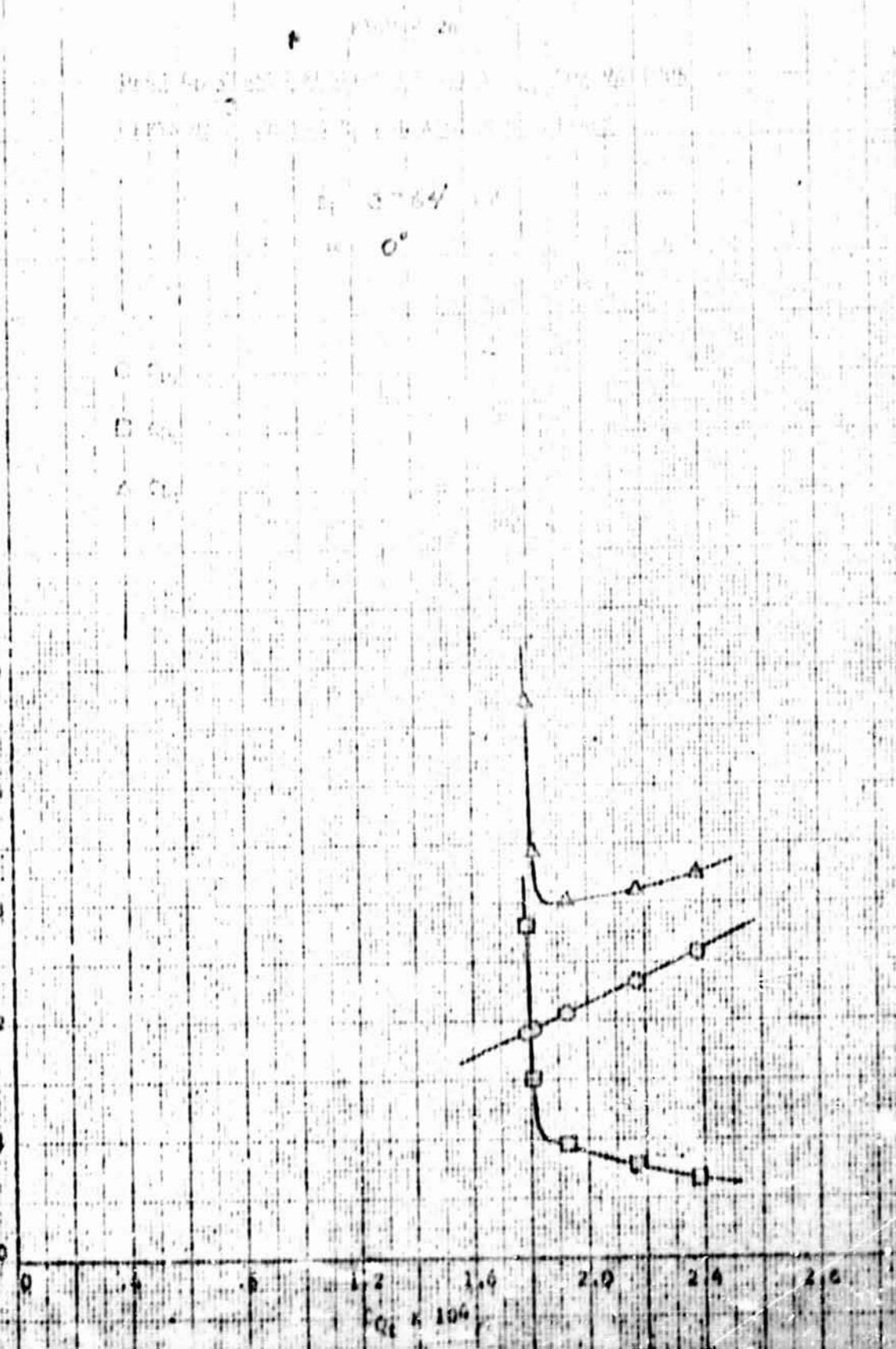


L. H. G. TROTTER

PROPHETIC CONFIRMATION IN THE DIVISION

W. H. G. 1973

July 1993



L. W. GATES

DEPT. OF CHEM. & PETROLEUM
UNIVERSITY OF TORONTO

1963
EXPERIMENTAL
DATA FOR POLY(1,3-PHENYLENE)
MONOCHLORIDE

JULY 1963

1100-22

DSC (D.T.G.) THERMAL ANALYSIS OF POLY(1,3-PHENYLENE)

MONOCHLORIDE IN AIR AND AT 50°C. ± 10°C.

$T_1 = 375^\circ \text{C}$

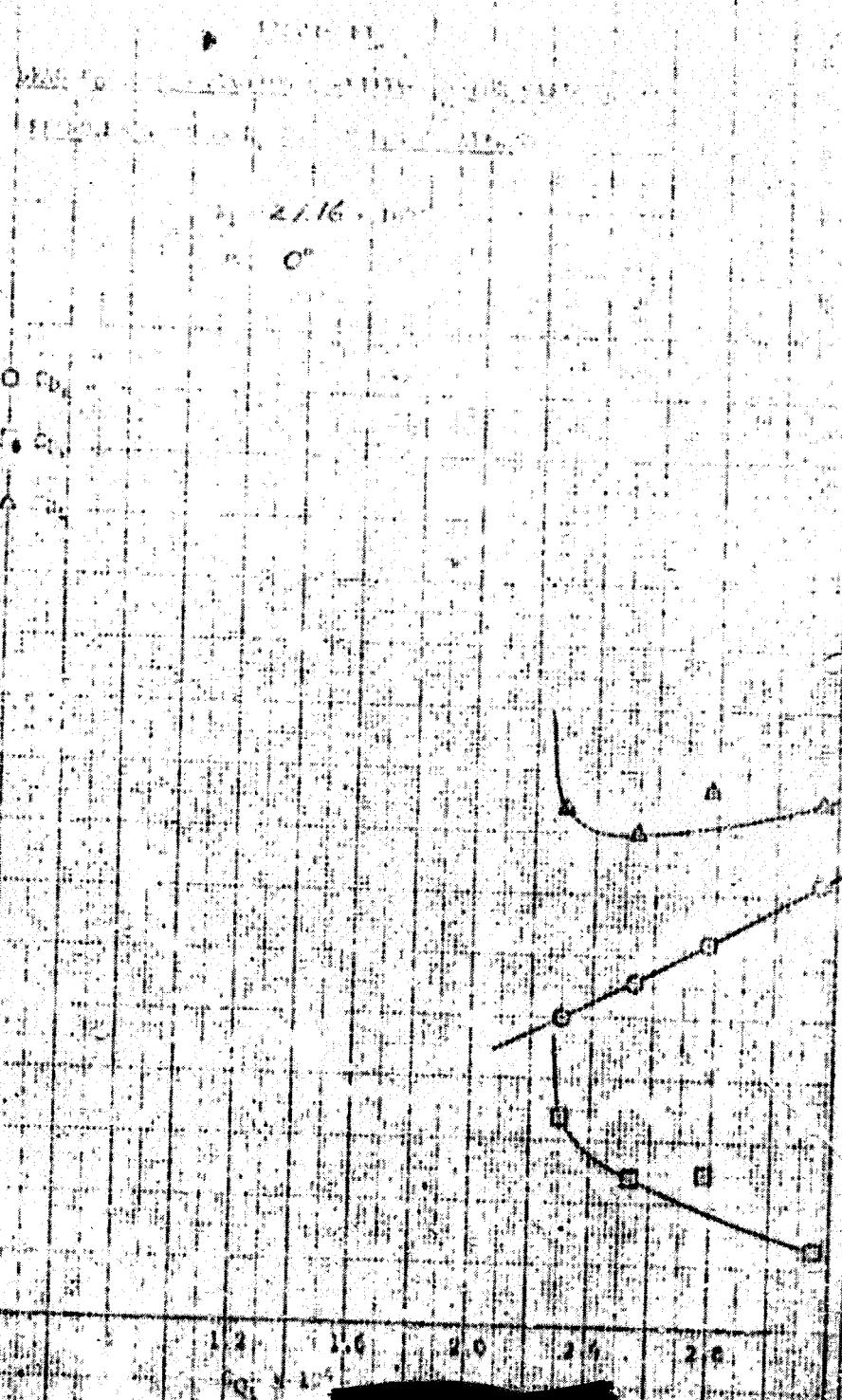
ΔH°



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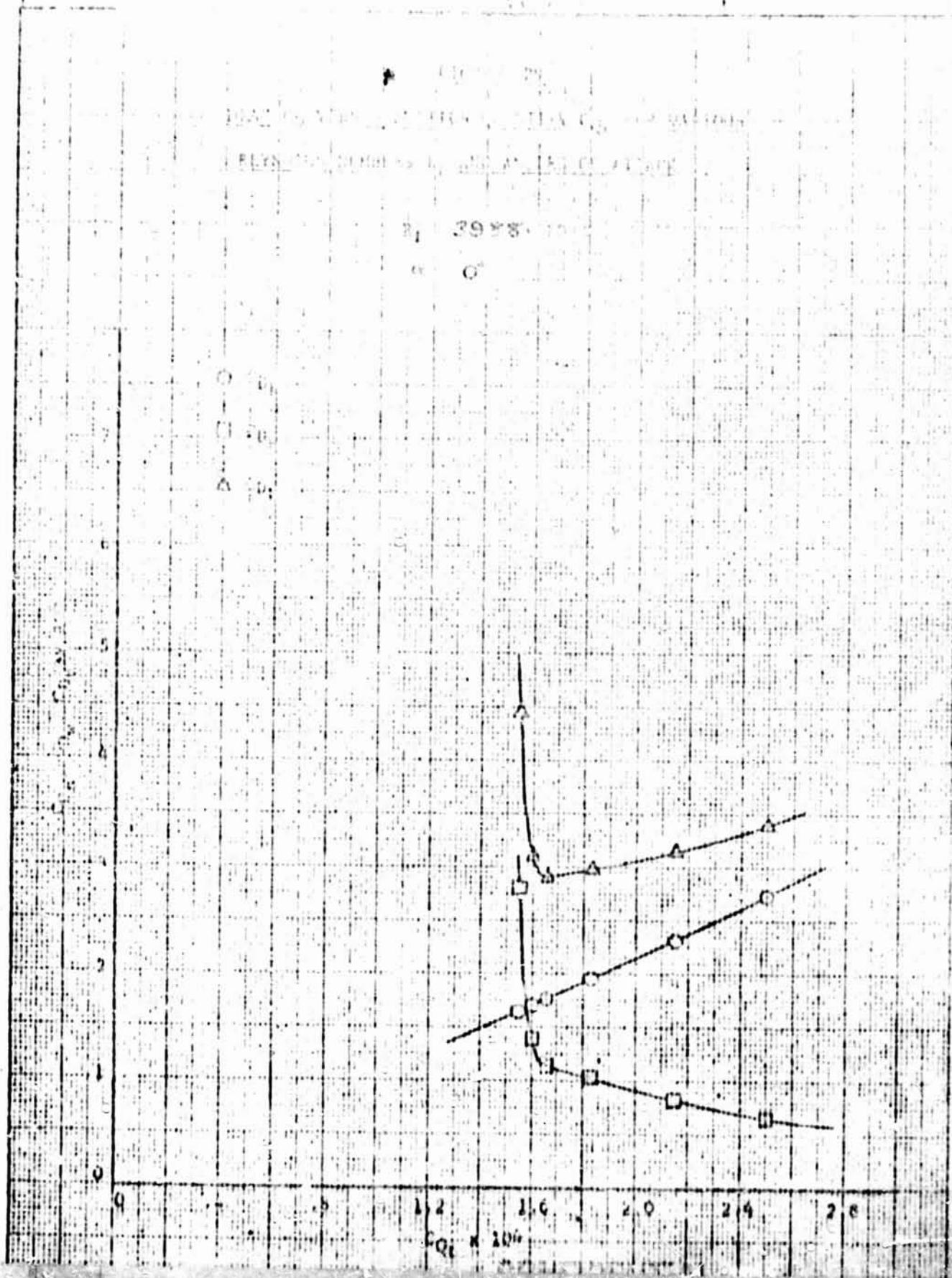
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Science Communication

1996-1997



Experiments

J. W. GORE

Chloro.

RESONANCE CONSTRUCTION
AND ITS DIVISION

DATE

July 1951

1.0000

Plot of ΔE versus $C_{O_2} \times 10^6$ and α

For $\alpha = 0^\circ$ and $\beta = 180^\circ$

$\alpha = 40^\circ$

$\alpha = 0^\circ$

C_{O₂}

D_{O₂}

A_{O₂}

5

4

3

2

1

0

0 0.4 0.8 1.2 1.6 2.0 2.4 2.8

$C_{O_2} \times 10^6$

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0.6000

0.4000

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1. W. F. Brink
C. G. Smith
DATE
July 1963

FLUORESCENCE
MONITOR DIVISION

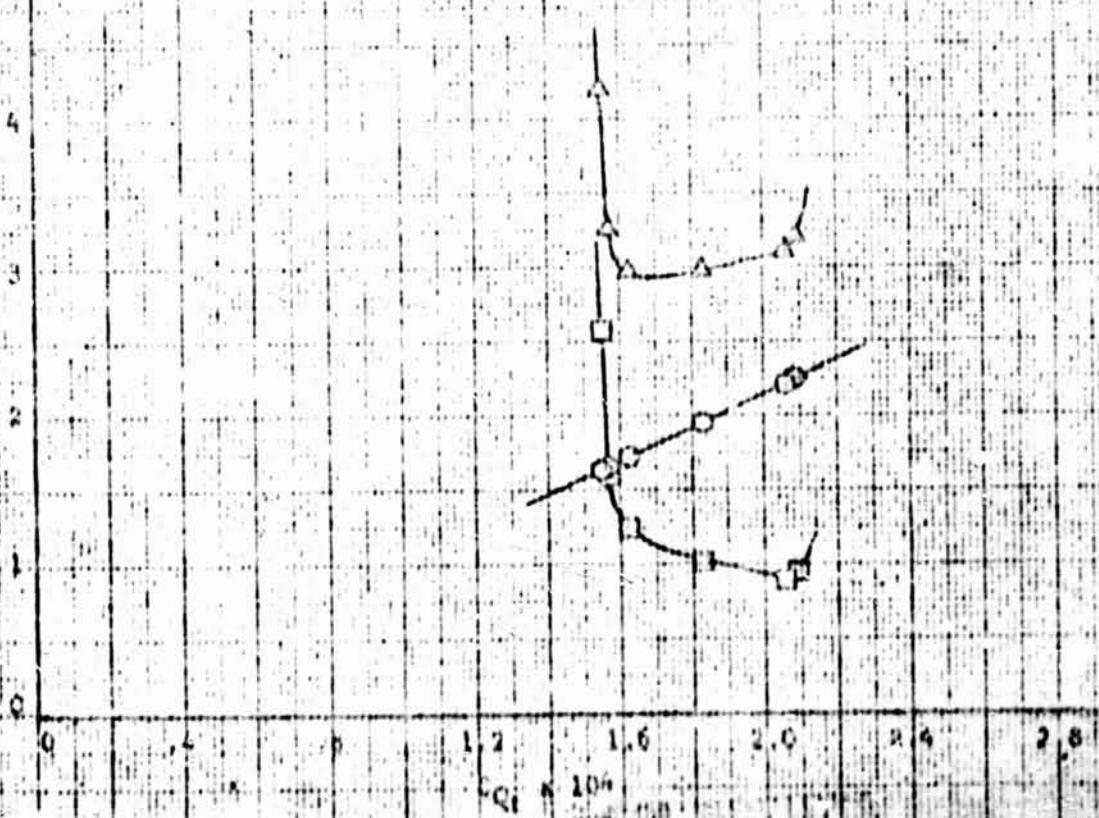
53
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JULY 1963

TRACER A

$E_1 = 42.35 \text{ keV}$

$\theta = 0^\circ$

Q. SP.
D. SP.



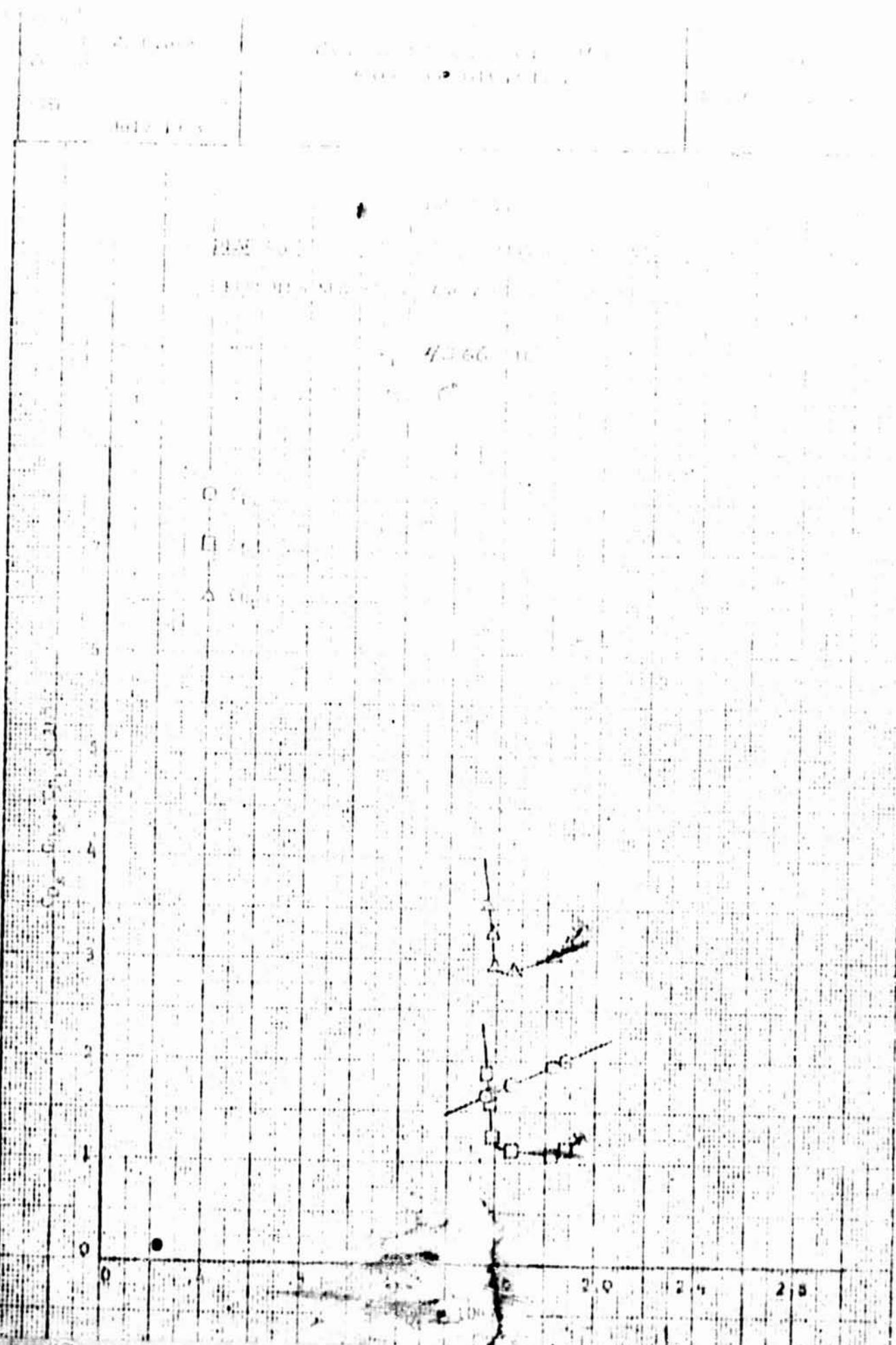
1948 - 1949 - 1950 - 1951 - 1952

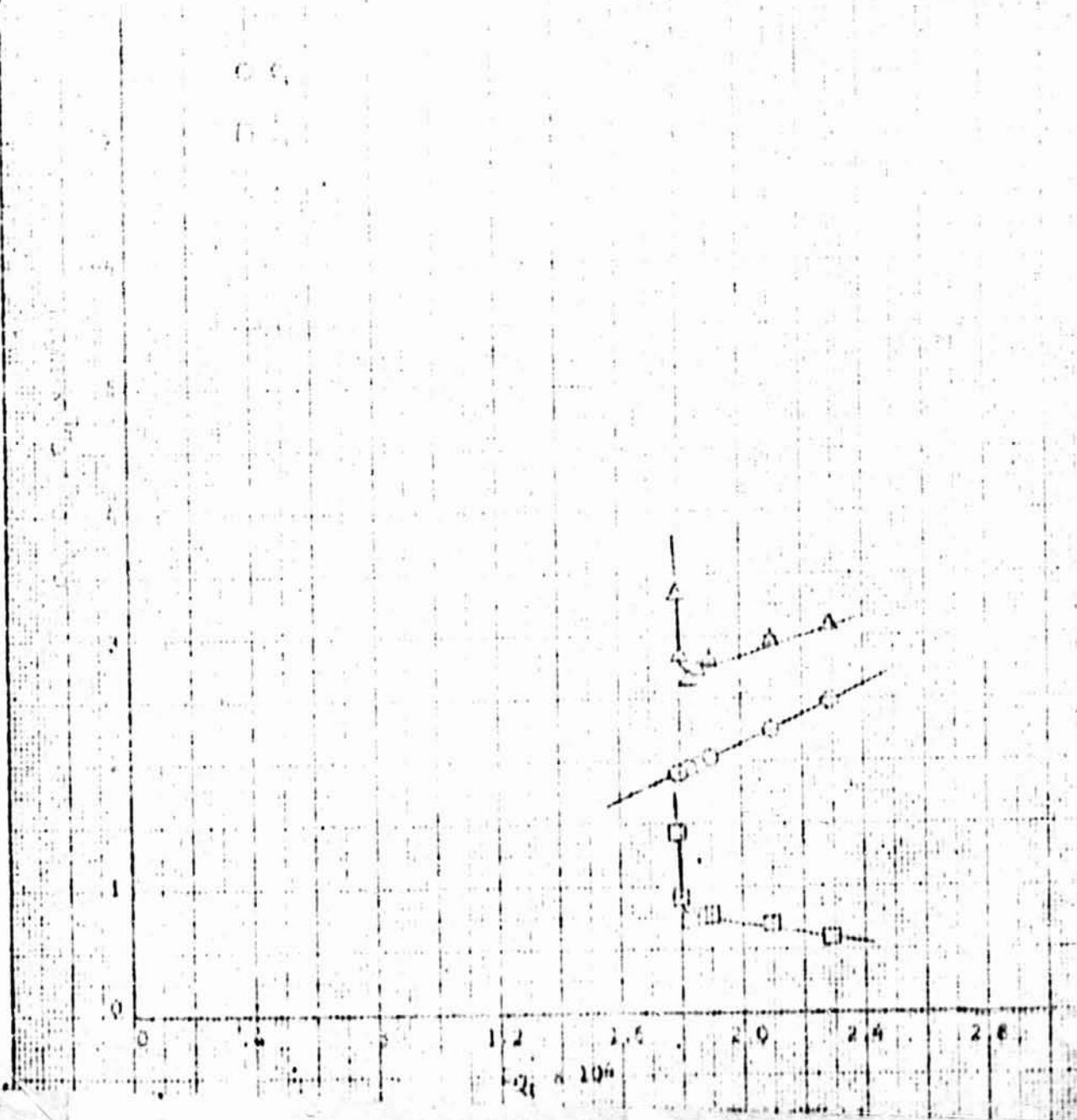
1948 - 1949 - 1950 - 1951 - 1952

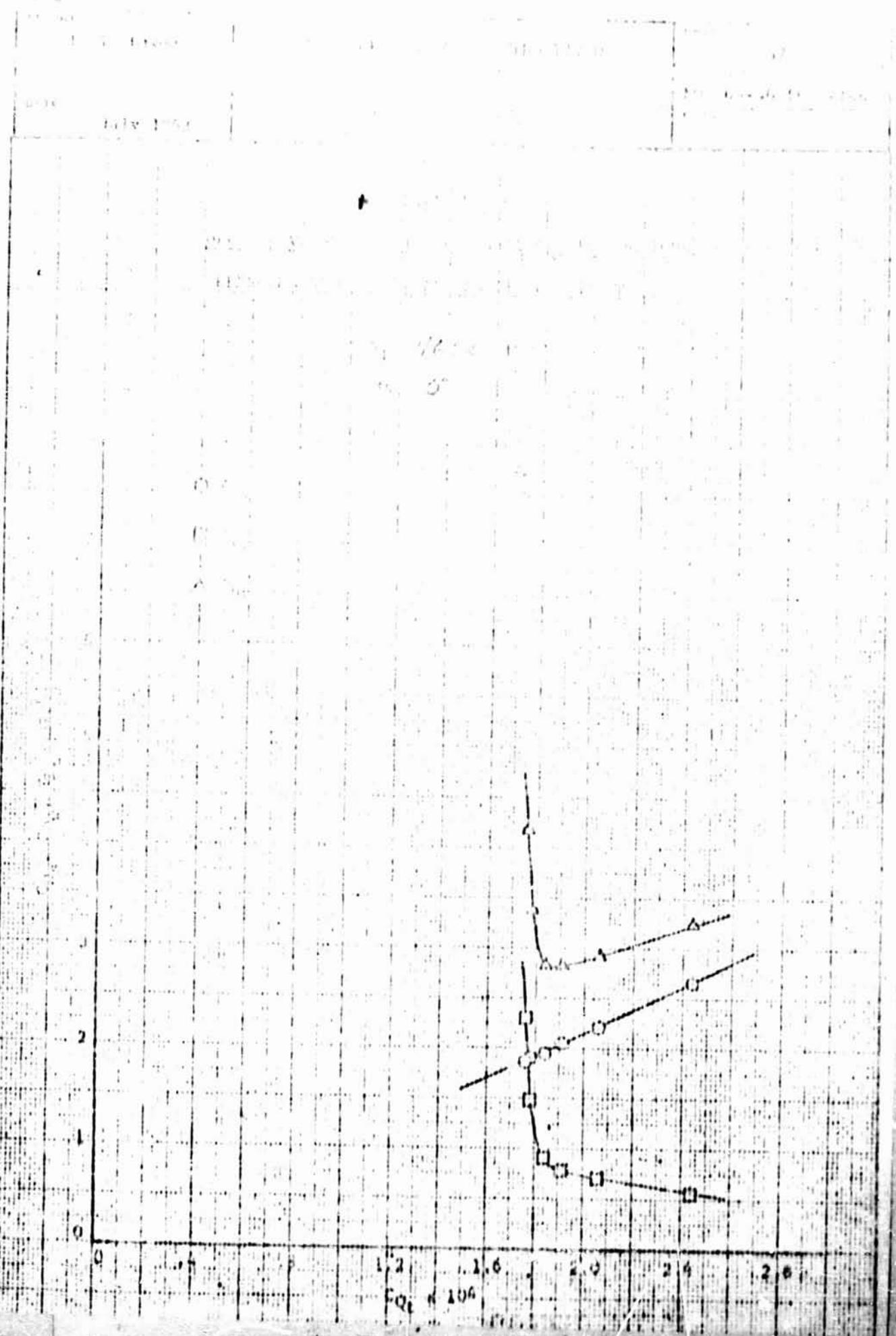
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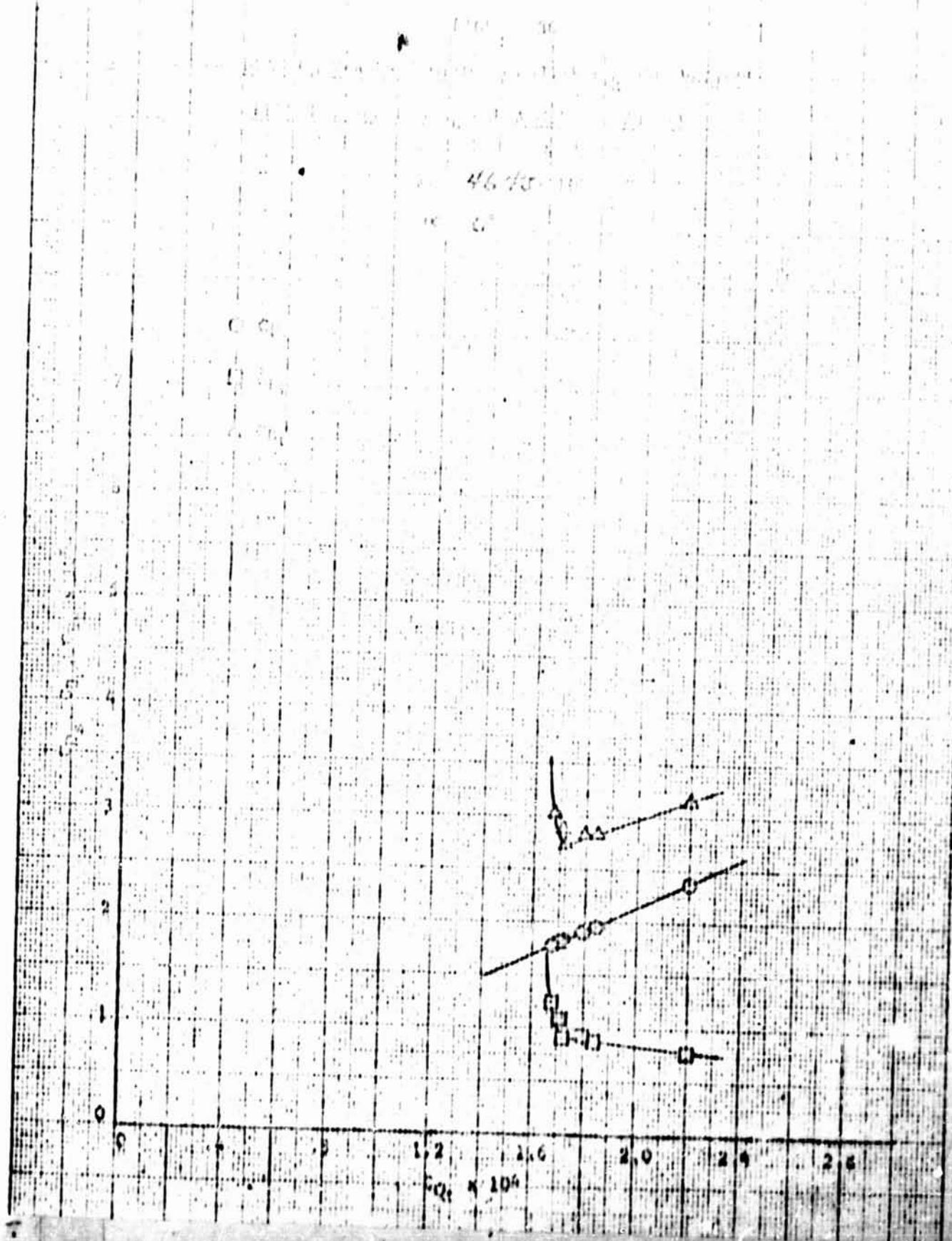




L. D. Clegg
Editor

The First Conference of Ecclesiastical Division

1933



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